STUDIES ON THE EFFECTS OF THERMAL EFFLUENTS ON THE PHYSIOLOGY OF SELECTED SEAWEEDS

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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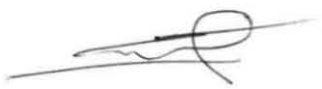
COCHIN, INDIA

AUGUST 1998

To my wife
Dear Safra

CERTIFICATE

This is to certify that this thesis " Studies on the effects of thermal effluents on the physiology of selected seaweeds " is a bonafide original research work conucted by Mr. GULSHAD MOHAMMED under my supervision and guidance. I further certify that no part of this thesis has previously formed the basis for th e award of any degree, diploma, associateship, fellowship or other similar titles or recognition.



Cochin 14,
August 1998.

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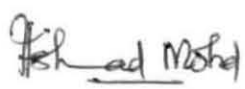
DECLARATION

I hereby declare that the thesis entitled " Studies on the effects of thermal effluents on the physiology of selected seaweeds " is a record of original and bonafide research carried out by me under the supervision of Dr.V.S.K.Chennubhotla. I also declare that no part of the thesis has been presented for award of any other degree, diploma, associateship, fellowship or other similar recognition.



GULSHAD MOHAMMED

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CONTENTS

PREFACE

The Tuticorin Thermal Power Station (TTPS) produces 1050 MW of electric power which forms about 25% of the power needed by the state of Tamil Nadu. As a result of combustion of coal, large amount of hot water, waste water and flyash are dumped into the Tuticorin Bay everyday. This has caused extensive damage to the fragile marine ecosystem of Tuticorin which forms a part of the Gulf of Mannar Biosphere Reserve.

Much work on the effect of pollution from domestic, sewage and industrial waste on Indian coastal waters are available in the literature. The effect of thermal pollution on riverine systems are also well documented. However, detailed work on the thermal pollution in marine waters are lacking. This study, was therefore, promoted by a paucity of information on 1) the hydrography of the polluted areas of Tuticorin Bay, 2) the physiology of seaweeds in thermal stress conditions and 3) the heavy metal concentrations of seawater and sediments and bioaccumulation of seaweeds in thermally polluted waters.

Hydrogrpahy, physiology of selected seaweeds and heavy metal concentrations forms the three areas of present study. Seaweeds are considered as excellent indicators of pollution due

to their sessile nature, accessibility and ability to accumulate pollutants from the ambient waters. The species of seaweeds selected for the study are : Gracilaria verrucosa, Enteromorpha compressa and Chaetomorpha linum.

The chapter on hydrography deals with variation in parameters such as water temperature, salinity, nutrients and phytoplankton productivity. Data for a period covering two years from October 1987 to September 1989 were collected from 5 stations in Tuticorin Bay. Phytoplankton productivity in polluted and control sites were correlated with environmental parameters.

Physiology of seaweeds forms the content of Chapter 2. The major physiological variables studied were : productivity of macroalgae, chlorophyll content and biochemical constituents. The variation between stations and seasons were analysed and physiology of seaweeds correlated with independent variables. Protein, carbohydrate and lipid of seaweeds are the biochemical constituents analysed.

Chapter 3 deals with the heavy metals of seawater, sediment and seaweeds. Copper, lead, nickel, zinc and iron were estimated and variations in space and time recorded. The bioaccumulation by seaweeds were correlated with hydrography, metals in seawater and

sediments. Linear regression equations were established for accumulation by algae with metal content of seawater.

A summary of the important findings and literature cited in the text are presented. The present study is intended to understand the level of pollution by TTPS on the marine algal vegetation of Tuticorin Bay. It is hoped that the information generated by this study would stimulate research in fields that require urgent attention for maintaining the biodiversity of this sensitive ecosystem.

ACKNOWLEDGEMENT

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The support and cooperation rendered by my parents and brother and relatives are also highly appreciated. Finally, I owe much more than I can to my wife Safra for her help and encouragement throughout research period to bring out this piece of work. The affection and love of my son Mohammed Shahbaz gave me moral courage.

Chapter 1

Hydrography

INTRODUCTION

The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) defines marine pollution as "the introduction by man, directly or indirectly of substance or energy into the marine environment including estuaries which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of seawater and reduction of amenities" (GESAMP, 1984).

Thermal (heat) is one of the seven major categories of environmental pollutant. Thermal pollution is "any change in natural water temperature that adversely affects the aquatic environment". Thermal power plants may contribute significantly towards economic growth but they may bring associated ills of environmental pollution. The largest single industrial use of water is for cooling purposes (Cairns, 1956) and vast quantities of water heated in this way are discharged into natural bodies of water.

The main sources of thermal effluents from thermal power stations are; cooling water, waste water from water treatment plants and condenser cleaners, waste water contaminated with petroleum products such as oil and grease, water from hydraulic ash disposal system and water collected inside the territory of

the power stations (Sarin, 1988). Thermal pollution due to cooling water, waste water and fly ash slurry discharges are bound to have detrimental effects on the hydrography of the receiving waters.

The Tuticorin Bay (08^{o} 45'N and 78^{o} 12'E) is situated in the southeast coast of India in the Gulf of Mannar along the Tamil Nadu coast. Tuticorin Bay encloses a water area of 56 sq.km. The Hare Island forms the eastern boundary of the Bay and Tuticorin land mass is on its western side. The southern point of Tuticorin Bay extends to a creek with wide mangrove area and a fresh water creek.

Tuticorin Thermal Power Station (TTPS) was commissioned in 1978, at an area of about 160 hectares and produces 1050 MW electricity per day (Plate 1). TTPS is located 2 km to the east of Tuticorin Port and the northern boundary of the complex is on the brim of the intertidal area of the Tuticorin Bay. The hot water effluent generated by cooling the condenser is pumped directly into the Bay (Plate 2). In addition there are waste water outlets also located 1 km westwards of the hot water outlet (Plate 3). Marine pollution is also caused by the seepage and overflowing of flyash slurry from the flyash pond(Plate 4). The amount of hot effluent water dumped into Tuticorin Bay is approximately 3780 tons/day and the waste water effluents discharged is 54 tons/day.

Before commissioning of TTPS, the Tuticorin Bay and its adjacent areas supported rich flora and fauna such as seaweeds, seagrass beds, mangroves and corals. The pollution from TTPS over the years has created a barren intertidal area almost devoid of seaweeds and seagrass beds (Plate 5). This has changed the once blue clear waters of Tuticorin Bay into an area with high turbidity and a bottom muddy non productive area (Plate 6).

In keeping the above aspects in perspective the present study was carried out to understand:

i) the effects of thermal effluents on the surrounding seawater and

ii) the consequences of changes in hydrography on plankton productivity.

A total of five stations were fixed to compare the hydrography of polluted and control sites of Tuticorin Bay. Hydrographical parameters such as water temperature, salinity, dissolved oxygen, pH, nutrients and primary productivity were studied for two years from October 1987 to September 1989.

Hydrography of the Tuticorin area has been studied with importance to inshore waters (Marichamy et al., 1985; Gopinathan and Rodrigo, 1991) and the oyster beds of Tuticorin Bay (Rajapandian et al., 1990). The physical and chemical parameters of Gulf of Mannar has also been reported (Chandrasekaran and Sudhakar,

Plate 1: Tuticorin Thermal Power Station produces 1050 MW electric power for the state of Tamil Nadu.

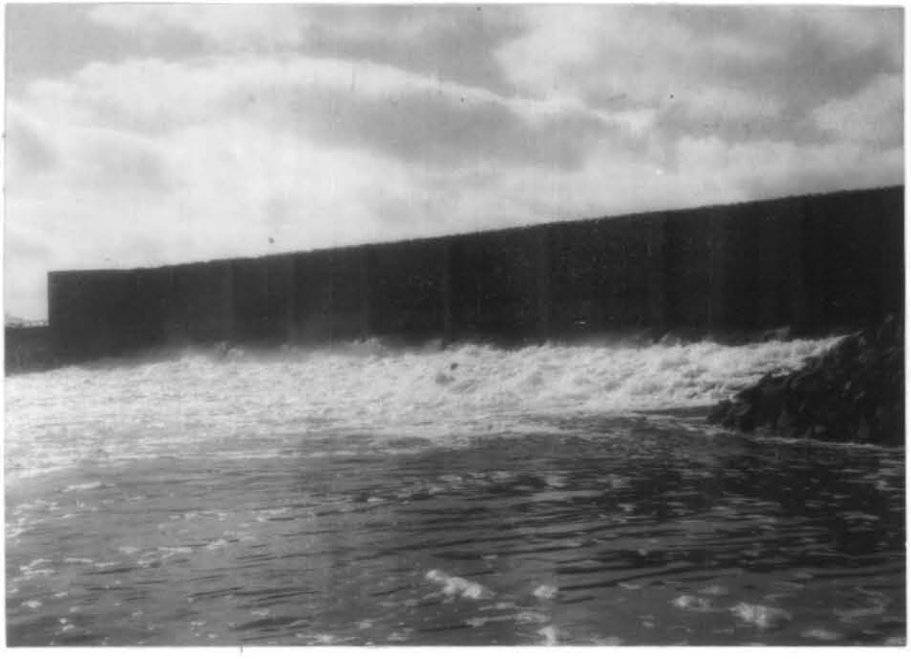


Plate 2: Hot water effluent from power station flowing directly into Tuticorin Bay. Average water temp. is 40 C.

Plate 3: Waste water effluents discharged into intertidal area. The thermal power station is in the background.

Plate 4: Flyash slurry overflowing the flyash pond dyke and mixing with the Bay waters.

Plate 5: The only vegetation found near the waste water effluent site. The coastline of Tuticorin is in the background.

Plate 6: Greyish brown water (flyash slurry) in the foreground and clear blue waters of the Bay in the background.

1968; Marichamy and Siraimeetan, 1979). Due to their economic importance extensive ecological studies of the edible oyster and pearl oyster beds of Tuticorin is also available in the literature (Mahadevan and Nayar, 1987; Nayar and Mahadevan, 1987).

The increasing use of coastal oceanic water for the cooling of electricity generating stations both nuclear and fossil fuel has raised many environmental questions. Prominent among them is the question of thermal pollution on the ecosystem to which the discharge takes place. The early works on thermal effluents and its impact on the macroalgae and seagrasses was reported from Florida (Zieman and Wood, 1975; Langford, 1982), Hawaii (Coles et al., 1982), Guam (Hohman and Tsuda, 1973), Puerto Rico (Kolehnainen et al., 1975) and Gulf of Mexico (van Tine, 1981). Satpathy et al. (1986) described the influence of hot water effects on the coastal waters of Kalpakkam near Madras. Balani (1975) studied the temperature of seashore waters near Tarapur Atomic Power Station, Bombay and noticed that the temperature at the discharging point is higher than the intake point. The hydrography and effects on power station heated effluents on distribution of sedentary flora and fauna near Madras Atomic Power Station was reported by Ahmed et al. (1992).

A computer literature search spanning more than 12 years from 1983, revealed that there is no work conducted to understand the influence of thermal pollution on hydrography. In India,

there are very few works in this area mainly because there are only a few power stations which discharges hot water effluents to the coastal waters.

MATERIALS AND METHODS

A preliminary survey was conducted in the Tuticorin Bay in and around the effluent site of TTPS. The major criteria for fixing the stations were accessibility and presence of seaweeds. The effluent sites are accessible only by boat from the western side of the Tuticorin Bay along the land mass. The sampling stations cover an area of 10 kms in the intertidal zone from the hot water site to Terespuram End. Based on this survey five stations were fixed one each in the hot water area, waste water area and two intermediate stations and a control site (Fig. A).

Station 1 : The hot water is discharged from TTPS directly into the Bay through big pipes. This station was selected 250 meters away from the discharge point. The water at this site is foamy, possibly due to the chemical reactions of anti-fouling and anti-corroding agents used in the coolant waters. Water is clear and the bottom to a depth of 3 meters is visible. The bottom is devoid of any vegetation and comprises mostly of soft, gray settled flyash sediments.

Station 2 : This station is located 1 km away westwards of station 1. This is the main waste water discharge area of TTPS.

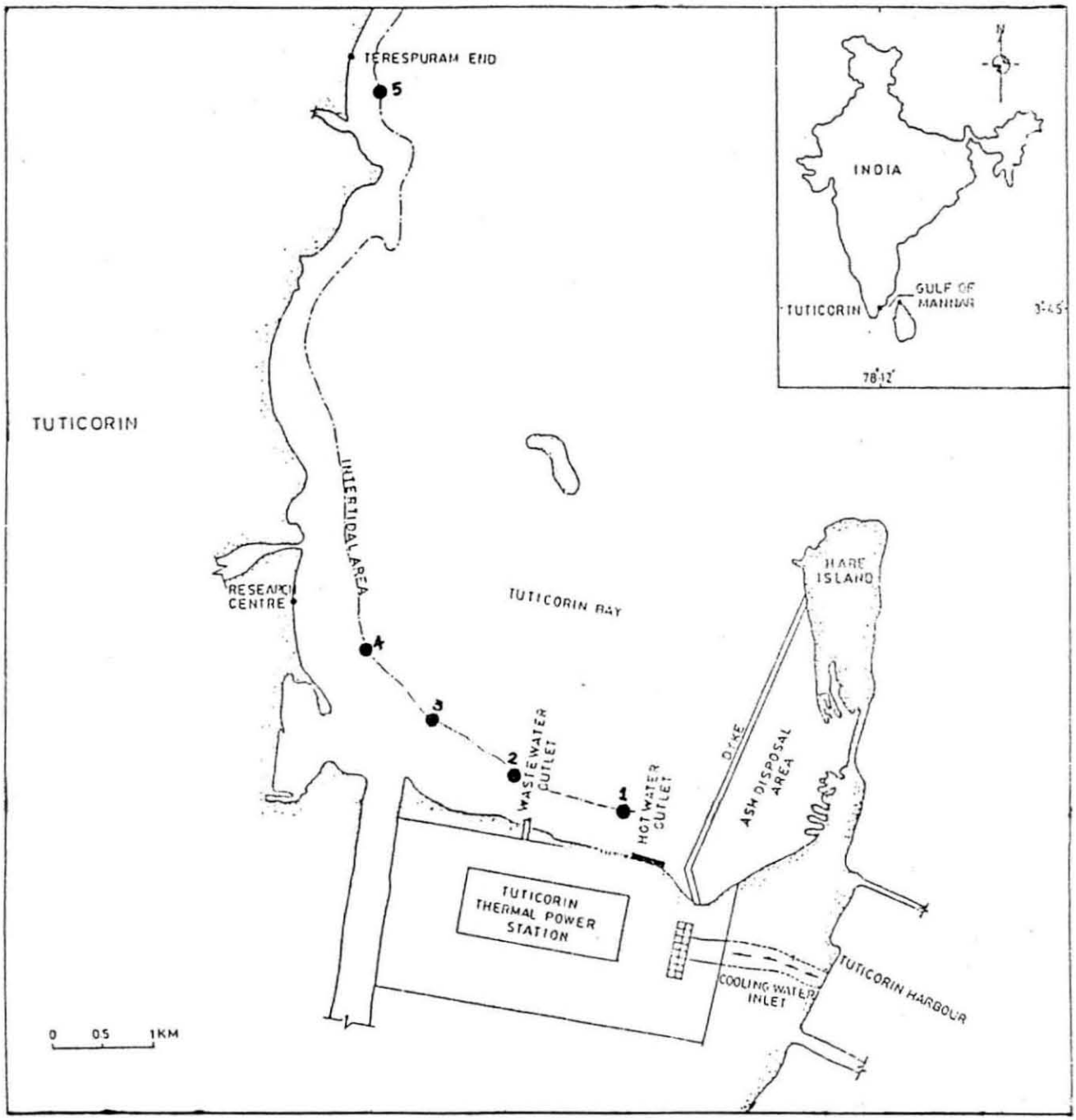


Fig. A : Map of the study area indicating sampling stations.

Waste water collected from different sources is stored in waste water storage tanks and released to the intertidal area through big pipes for 1 hour in the morning. The bottom is soft, gray and muddy. Patches of seagrass beds of comprising mainly of the species Halodule uninervis are noticed and closer to the shore macroalgae such as Gracilaria verrucosa, Enteromorpha compressa and Chaetomorpha linum are found.

Station 3 : Located 1 km northwest of station 2 and 1 km away from the shore. The total depth at this station during high tide is 3-4 meters. Continuous seagrass beds of Halodule uninervis and Cymodacea serrulata are seen. The dominant seaweeds noticed are : Gracilaria verrucosa, Hypnea musciformis, Enteromorpha compressa and Chaetomorpha linum. Water is clear and the bottom is mainly sandy. This station is 'healthy' in comparison to stations 1 & 2.

Station 4 : This station is located 1 km northward of station 3. The depth is 2-3 meters during high tide and the water is clear and the bottom is mainly sandy. In addition to seaweeds and seagrasses found in station 3, Padina gymnospora, Acanthophora spicifera and Gracilaria eudlis are also noticed at this station.

Station 5 : It is the farthest station from the hot water effluent site and situated 6 km away from station 4. This station

does not have any influence of pollution and it is considered as the control site for the present study. Seaweeds and seagrasses are more luxuriant than at stations 3 & 4.

Water samples were collected at all the stations just below the surface of the water column. Sampling was carried out fortnightly for a period of two years from 1987 October to 1989 September. Water samples collected in 1 litre plastic bottles were kept in dark, cool conditions till the time of analysis on the same day.

Water temperature was measured in the field using a calibrated thermometer. Salinity was determined by Mohr's titration method (Strickland and Parsons, 1968). Dissolved oxygen was analysed by Winkler method (Anon., 1975). pH was determined using ECIL digital pH meter.

All nutrients except nitrate was analysed using the methods outlined by FAO (Anon., 1975) and measured in a spectrophotometer (ECIL GS 865 D). Nitrate was determined by modified method of Mullin and Riely (1955).

Phosphate : The phosphate in water was allowed to react with ammonium molybdate, forming a complex heteropoly acid. This was reduced by ascorbic acid in presence of antimonyl tartrate as

catalyst into a blue coloured complex, the light absorption of which is then measured at 880 nm.

Nitrate : To the water sample a buffer reagent (phenol + sodium hydroxide) and a reducing agent (copper sulphate + hydrazine sulphate) was added and kept in dark for 20 hrs. This reduced solution is treated with sulphanilamide and NNED and the intensity of colour developed is measured at 545 nm.

Silicate : Determination of silicate is based on the formation of a yellow silicomolybdic acid, when a more or less acidic sample is treated with a molybdate reagent. Since this acid is rather weak in colour, they are reduced by ascorbic acid to intensely coloured blue complexes. Absorbance of the sample is measured at a wavelength of 810 nm.

Turbidity : Nephelometric method using a turbidimeter was employed to estimate the extend of turbidity. The intensity of light scattered by the sample was compared with intensity of light scattered by a standard reference suspension. Values are expressed in Nephelometric Turbidity Units (NTU).

Primary production : Light and dark bottle oxygen technique (Gaarder and Gran, 1927) was employed for measuring the primary production. After 4 hrs of exposure to light the samples were

fixed by Winkler's method for the estimation of oxygen. Productivity was calculated after converting into carbon equivalents employing the factor 0.536/1.25. The results are expressed in gC/cub.m/day.

The data were grouped into 3 seasons : Premonsoon (June to September), Monsoon (October to January) and Postmonsoon (February to May).

RESULTS

Seasonal averages of hydrographical parameters at station 1 to 5 are given in Table 1. Water temperature at station 1 was higher than all the other stations. Dissolved oxygen at station 1 and 2 were lower by 1 to 2 ml/l in comparison to other stations. Salinity and pH did not show much variations between stations. Phosphate showed high values during postmonsoon at station 1 while at other stations higher average values were noticed during premonsoon. Postmonsoon and premonsoon months show greater values of nitrate than the monsoon months. Distinct increase in silicate is noticed during postmonsoon at all stations. Turbidity values were high during monsoon. There was no net production by phytoplankton at station 1 and comparatively higher values were obtained at stations 4 and 5. Respiration values are higher at station 1 eventhough net production was nil.

The results of heirarchial ANOVA are presented in Table 2. Hydrographical parameters did not vary significantly between years and except for silicate ($P < 0.01$) the variations between season is also not significant. However, variations within stations were significant for most parameters studied. The effect of environmental parameters on net productivity is presented in Table 3. Net production is not significantly related to hydrographical factors in stations 1 and 2. At station 3 a positive significant relationship is noticed with phosphate and nitrate, while at station 5, significant relationship is noticed with silicate and dissolved oxygen. A linear negative relationship is observed between water temperature and net production at station1. The equation being :

Net production = 0.3654 - 0.0088 Water temp. $r = -0.52$, $n = 24$

The monthly variations in different parameters studied at stations 1 and 5 are depicted in Figures 1A to 5B. Distinct differences are noticed in the fluctuations of water temperature, dissolved oxygen and net production. The variations in nutrients at stations 1 and 5 seems to follow a uniform pattern at both the stations. Turbidity at station 5 is comparatively higher than that of station 1. Net production at station 1 varied between 0 and 0.1 and station 5 between 0.31 and 1.82 gC/cub.m/day. The relationship between water temperature and net production at station 1 is shown in Fig. 6. Increase in values of temperature during March to May is coupled with net production being nil at the same period.

Table 1 : Seasonal averages of hydrographical parameters at Stations 1 to 5.

Parameter	Season	Station				
		1	2	3	4	5
Water temp. (deg.C)	Premonsoon	38.3	30.7	28.7	28.8	28.4
	Monsoon	39.2	32.3	29.9	29.5	28.7
	Postmonsson	39.7	32.3	30.1	29.8	29.3
Salinity (ppt)	Premonsoon	35.0	31.8	33.7	33.4	34.7
	Monsoon	33.2	30.0	31.0	31.3	32.1
	Postmonsoon	32.9	28.9	31.7	31.9	32.6
Diss. oxygen (ml/L)	Premonsoon	4.9	5.1	5.5	6.5	6.2
	Monsoon	4.8	5.1	5.7	6.3	6.5
	Postmonsoon	4.9	5.1	5.6	6.2	6.3
pH	Premonsoon	8.3	8.4	8.4	8.4	8.5
	Monsoon	8.4	8.5	8.6	8.6	8.6
	Postmonsoon	8.4	8.4	8.6	8.6	8.6
Phosphate (µg-at./L)	Premonsoon	0.7	2.4	2.0	2.2	2.0
	Monsoon	0.8	1.5	1.3	1.5	2.0
	Postmonsoon	1.8	1.7	2.1	1.3	1.3
Nitrate (µg-at./L)	Premonsoon	1.1	2.0	1.9	2.1	1.8
	Monsoon	0.6	1.3	1.3	1.6	1.9
	Postmonsoon	1.7	2.4	1.9	2.1	2.0
Silicate (µg-at./L)	Premonsoon	5.5	5.5	5.4	5.5	5.5
	Monsoon	4.0	4.3	4.3	4.2	4.5
	Postmonsoon	8.1	8.0	8.0	8.1	8.0
Turbidity (NTU)	Premonsoon	1.8	4.4	3.4	3.6	2.9
	Monsoon	2.1	6.8	5.1	4.1	3.4
	Postmonsoon	2.0	4.6	4.0	3.2	3.0
Net production (gC/cub.m/day)	Premonsoon	0.0	0.1	0.4	0.7	0.7
	Monsoon	0.0	0.1	0.3	0.4	0.4
	Postmonsoon	0.0	0.1	0.4	1.1	0.9
Respiration (gC/cub.m/day)	Premonsoon	0.3	0.3	0.4	0.6	0.4
	Monsoon	0.3	0.2	0.4	0.4	0.4
	Postmonsoon	0.3	0.3	0.5	0.7	0.8

Table 2 : Heirarchial ANOVA of hydrographical parameters.

Parameter		Year	Season/Yr	Station/ Season/Yr	Error
Water temp.	df	1	4	24	330
	F	1	29	220	2
	P	NS	NS	**	
Salinity	df	1	4	24	330
	F	21	100	25	8
	P	NS	NS	NS	
Diss. oxygen	df	1	4	24	330
	F	0.1	0.5	5	1
	P	NS	NS	**	
pH	df	1	4	24	330
	F	0.4	0.5	0.1	0.1
	P	NS	NS	NS	
Phosphate	df	1	4	24	330
	F	0.2	3	4	0.3
	P	NS	NS	*	
Nitrate	df	1	4	24	330
	F	0.2	7	2	0.3
	P	NS	NS	*	
Silicate	df	1	4	24	330
	F	1	227	0.3	2
	P	NS	**	NS	
Net prod.	df	1	4	24	330
	F	1	2	2	0.1
	P	NS	NS	**	
Respiration	df	1	4	24	330
	F	1	1	0.3	0.1
	P	NS	NS	*	

NS - Not significat * - P < 0.05 ** - P < 0.01

Table 3 : Correlation matrices of hydrographical parameters on productivity of phytoplankton at stations 2 - 5.

Parameters	WT	Sal	Oxy	pH	Pho	Nit	Sil	NP
Station 1								
Water temp.	1.00							
Salinity	0.38	1.00						
Diss. oxygen	-0.04	-0.05	1.00					
pH	0.04	-0.29	0.52*	1.00				
Phosphate	-0.07	-0.34	0.36	0.27	1.00			
Nitrate	0.23	0.28	0.10	-0.24	0.56*	1.00		
Silicate	-0.14	-0.20	0.33	0.13	0.77*	0.59*	1.00	
Net prod.	-0.15	0.17	0.35	-0.22	-0.08	0.12	-0.20	1.00
Station 2								
Water temp.	1.00							
Salinity	-0.28	1.00						
Diss. oxygen	-0.25	0.33	1.00					
pH	0.27	-0.46*	0.47*	1.00				
Phosphate	0.03	0.05	0.02	-0.09	1.00			
Nitrate	0.03	-0.53*	-0.13	0.03	-0.10	1.00		
Silicate	-0.03	-0.19	-0.02	-0.09	-0.19	0.88*	1.00	
Net prod.	-0.17	-0.08	0.28	0.22	0.34	0.07	0.01	1.00
Station 3								
Water temp.	1.00							
Salinity	0.20	1.00						
Diss. oxygen	-0.20	-0.45*	1.00					
pH	0.23	-0.27	0.51*	1.00				
Phosphate	-0.18	0.18	0.17	0.27	1.00			
Nitrate	-0.48*	0.08	-0.06	0.14	0.78*	1.00		
Silicate	-0.65*	-0.65*	0.31	-0.01	0.24	0.59*	1.00	
Net prod.	0.15	-0.34	0.31	0.09	0.54*	0.44*	0.31	1.00
Station 5								
Water temp.	1.00							
Salinity	0.21	1.00						
Diss. oxygen	-0.39	-0.28	1.00					
pH	0.66*	-0.09	-0.48*	1.00				
Phosphate	-0.29	0.06	-0.38	-0.36	1.00			
Nitrate	0.42*	-0.06	0.18	0.36	-0.37	1.00		
Silicate	-0.45*	-0.45*	-0.07	0.10	0.01	0.06	1.00	
Net prod.	-0.37	-0.40	0.41*	0.06	-0.38	0.04	0.79*	1.00

* indicates significant correlation

Fig 1A : Variations in water temperature at stations 1 and 5

Water Temperature

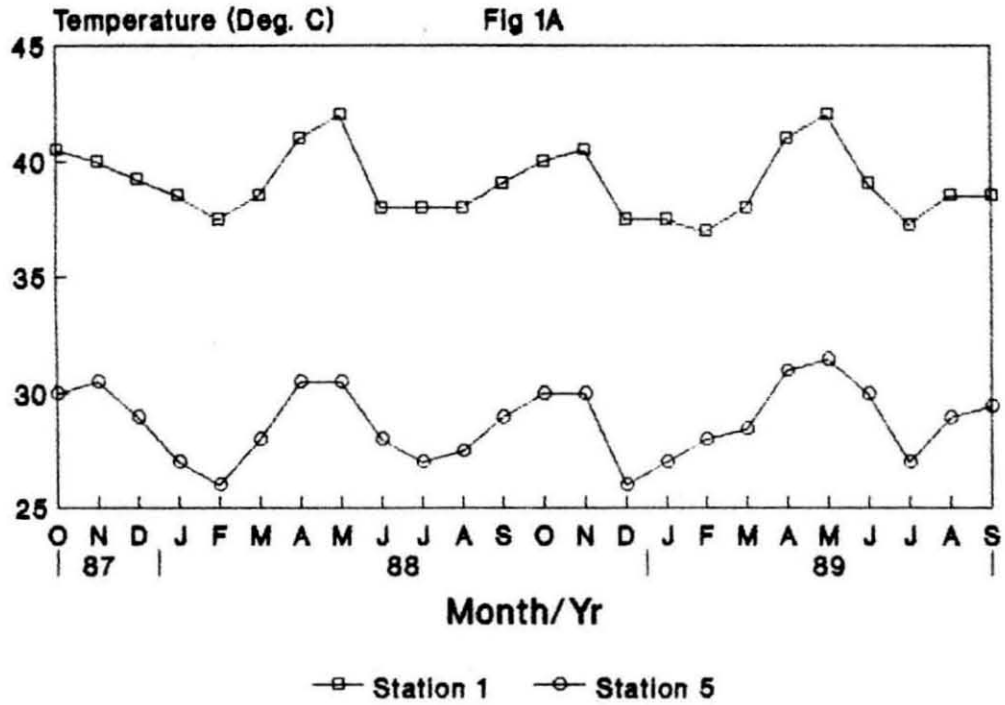
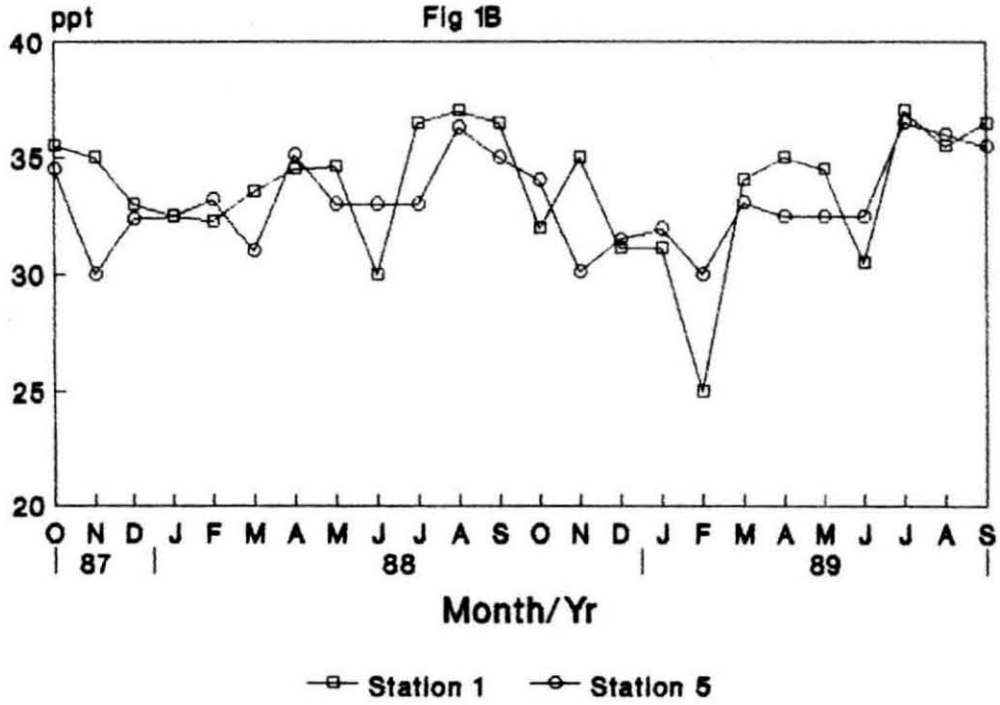


Fig 1B : Variations in salinity at stations 1 and 5

Salinity


ppt
Fig 1B
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35
30
25
20
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Station 1
Station 5

Fig 2A : Variations in dissolved oxygen at stations 1 and 5

Dissolved Oxygen

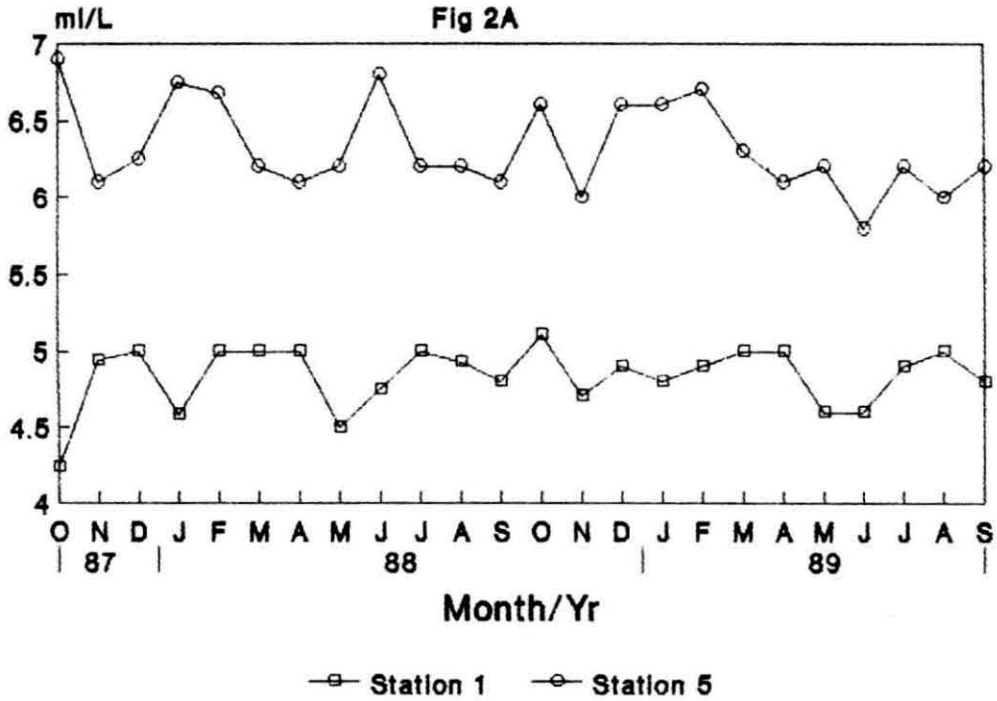


Fig 2B : Variations in pH at stations 1 and 5

pH

Fig 2B

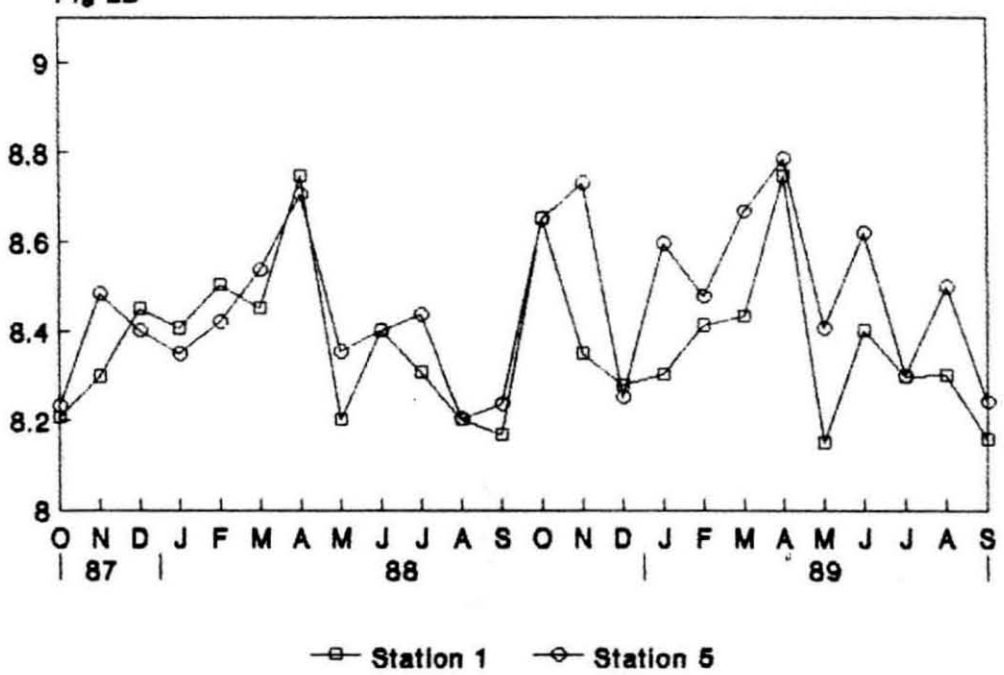

9
8.8
8.6
8.4
8.2
8
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Station 1
Station 5

Fig 3A : Variations in phosphate at stations 1 and 5

Phosphate

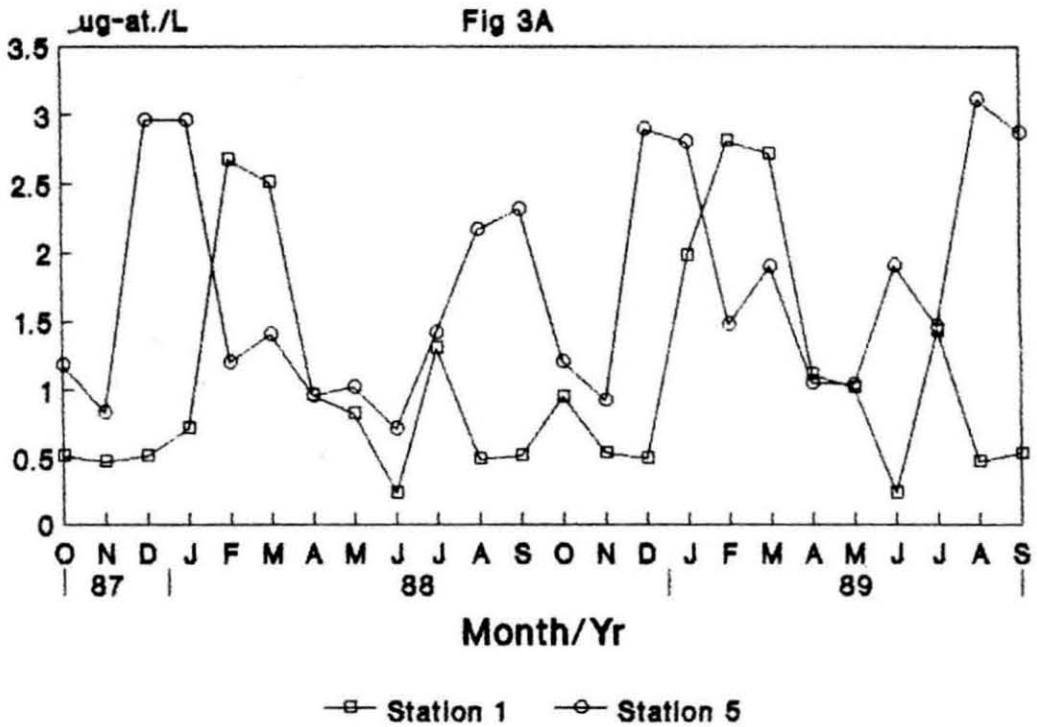

ug-at./L
Fig 3A
3.5
3
2.5
2
1.5
1
0.5
0
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Station 1
Station 5

Fig 3B : Variations in nitrate at stations 1 and 5

Nitrate

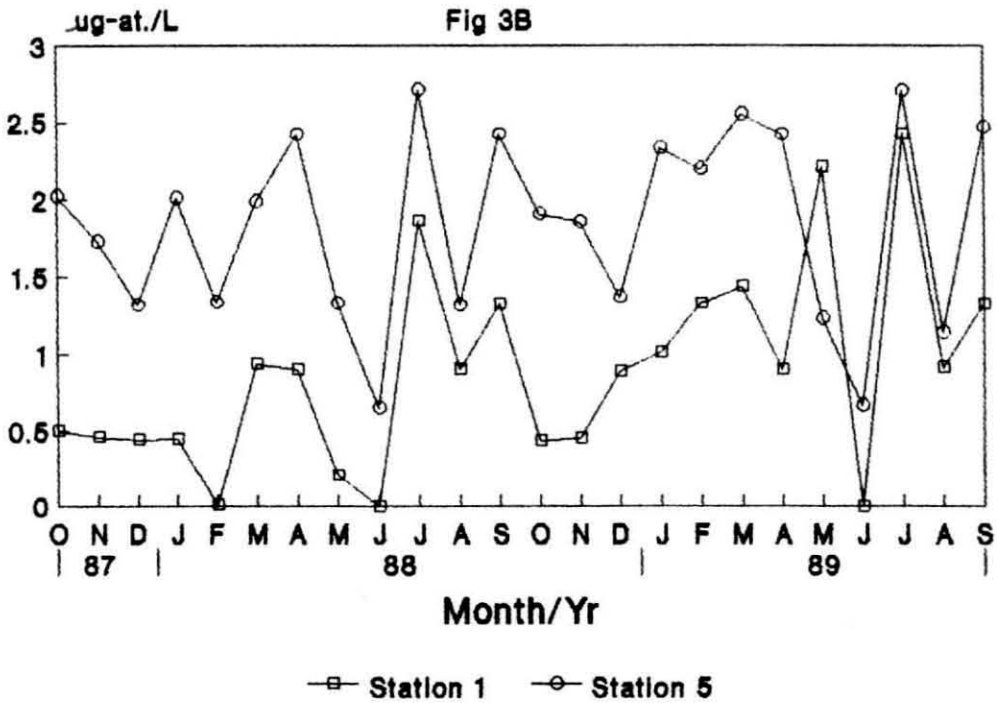

ug-at./L
Fig 3B
3
2.5
2
1.5
1
0.5
0
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Station 1
Station 5

Fig 4A : Variations in silicate at stations 1 and 5

Silicate

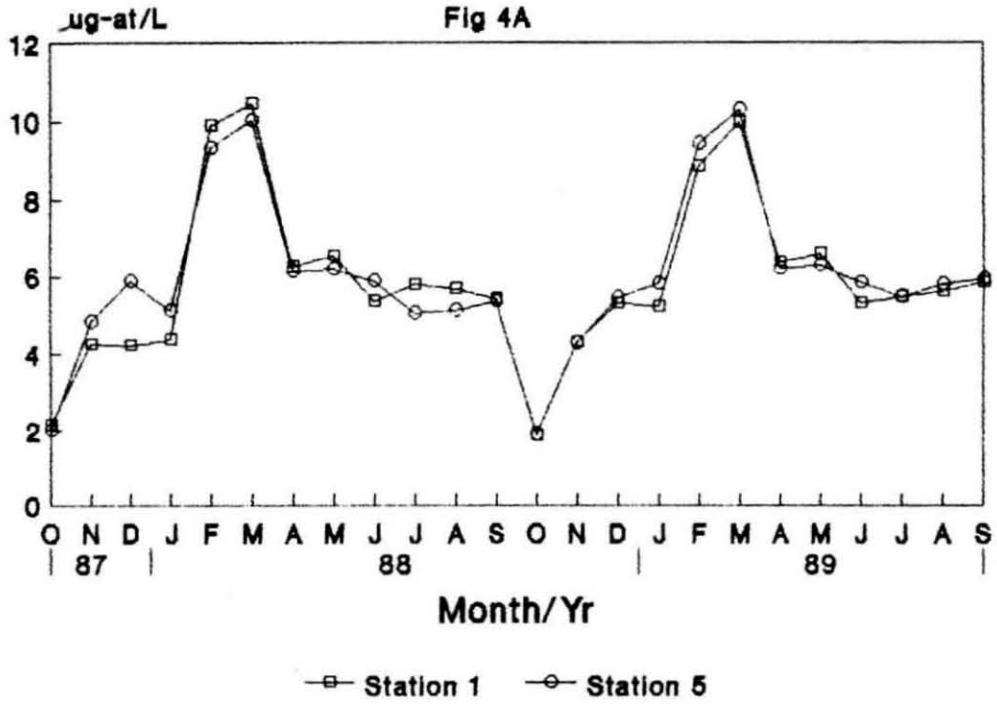

µg-at/L
Fig 4A
12
10
8
6
4
2
0
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Station 1
Station 5

Fig 4B : Variations in turbidity at stations 1 and 5

Turbidity

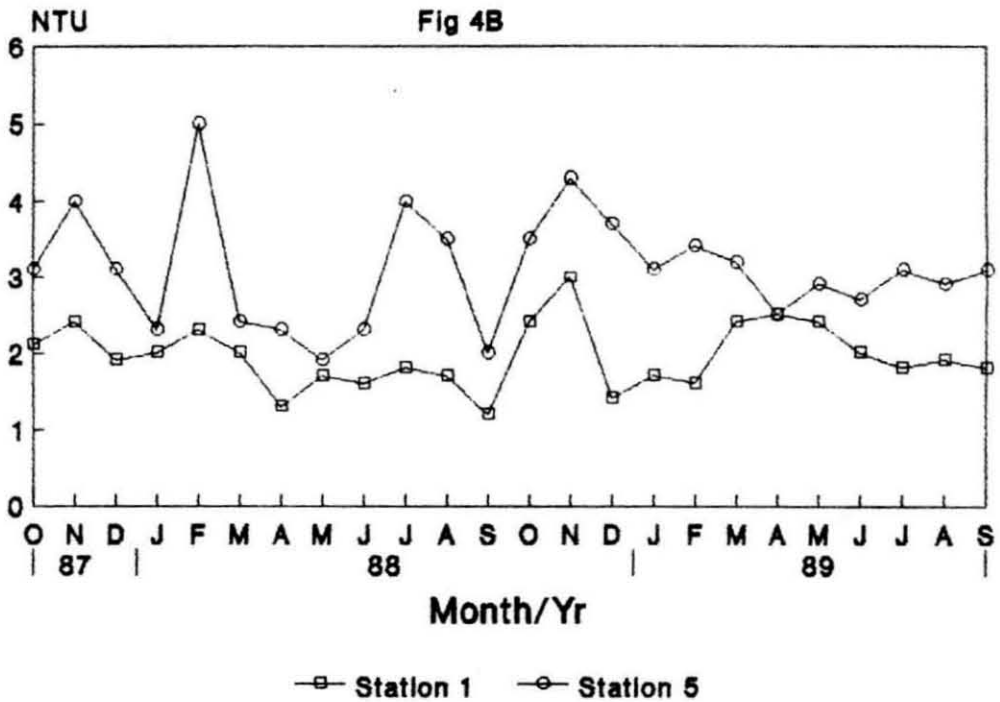

NTU
Fig 4B
6
5
4
3
2
1
0
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Station 1
Station 5

Fig 5A : Variations in net productivity at stations 1 and 5

Net productivity

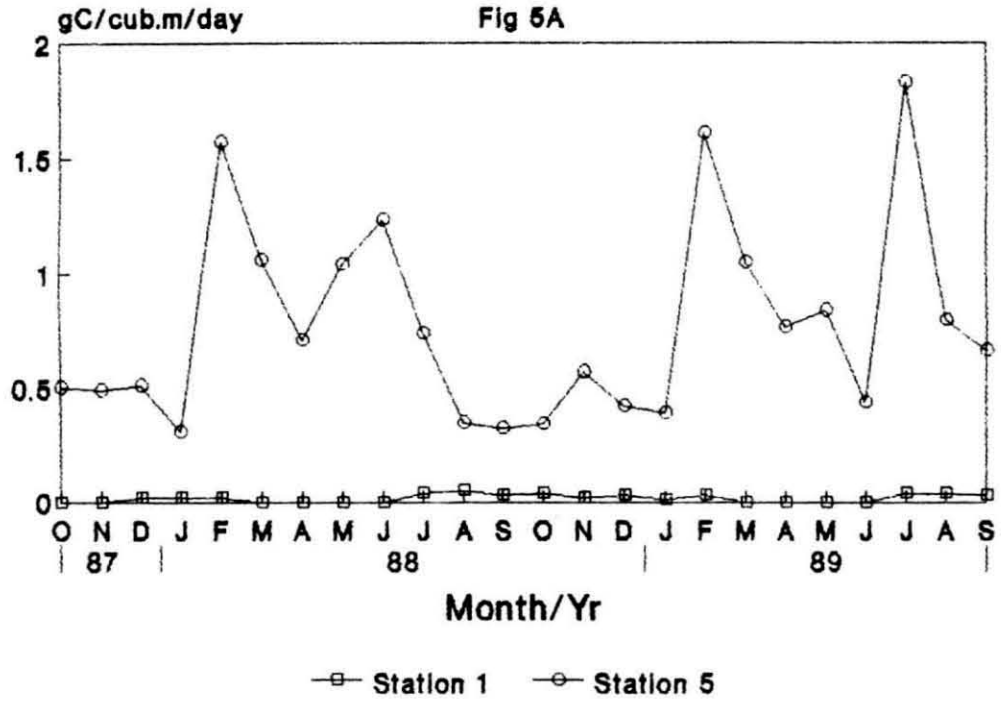


Fig 5B : Variations in respiration at station 1 and 5

Respiration

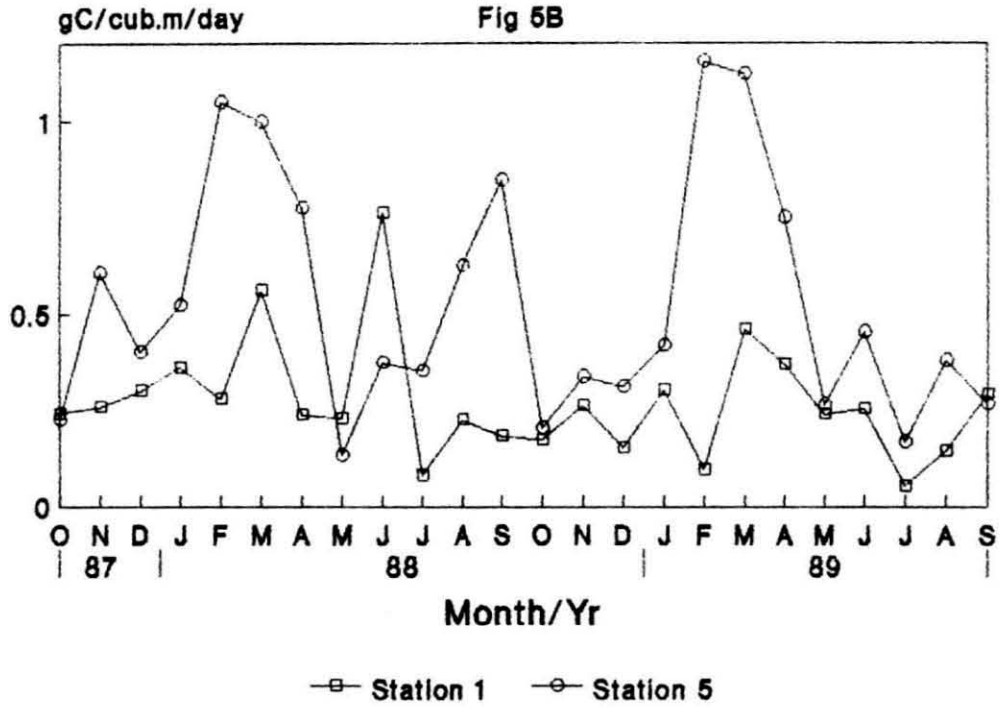
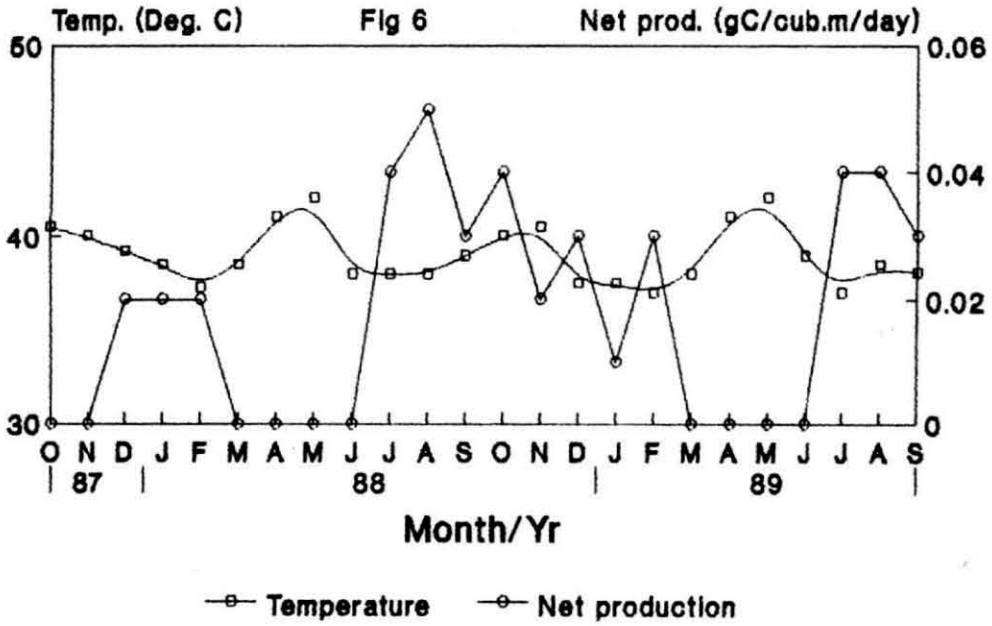


Fig 6 : Relationship between temperature and net production at station 1

Station 1


Temp. (Deg. C)
Fig 6
Net prod. (gC/cub.m/day)
50
40
30
0.06
0.04
0.02
0
O N D J F M A M J J A S O N D J F M A M J J A S
87
88
89
Month/Yr
Temperature
Net production

DISCUSSION

It is generally conceded that "temperature is the most important single factor governing the occurrence and behaviour of life" (Gunter, 1957).

The modifications of temperature at Tuticorin Bay due to the hot water effluent is quite extensive. The average monthly temperature rise in the Bay just off the hot water site is 10.3 to 11.5 ^{o}C. Blake et al.(1976) reported an increase of 4-7.2 ^{o}C at Tampa Bay, Florida. Devinny (1980) found 7-10 ^{o}C rise in hot water effluent at California. At Tarapur near Bombay, an increase of 9-10 ^{o}C than normal water was reported by Kamath (1980).

Satpathy et al.(1986) noted that when hot water is discharged into a receiving body, the discharge spreads out to form a plume in which the temperature decreases steadily from a maximum at the discharge point to reach the normal ambient temperature of the surrounding water at a distance. The shape, volume and temperature characteristics of the thermal plume depend upon the hydrographic features of the surrounding waters. Although detailed studies on thermal plume at Tuticorin Bay was not studied, preliminary analysis reveals that the hot water influence is felt approximately to a distance of 1 km. The increase in temperature is also noticed at station 2 which fall in the perimeter of the plume. The data collected during the preliminary

survey indicated that the plume also spreads eastwards of the discharge point upto a distance of 1 km. A seasonal change in the direction of plume is also noticed. The plume moves in a a northerly direction during the southwest monsoon period and in a southerly direction during the northeast monsoon. The southerly winds spreads the plume more to the westwards than the eastern side due to the presence of flyash pond dyke. During the northerly winds the plume moves outward into the Bay.

The maximum net primary production observed at the hot water effluent site is only 0.05 gC/cub.m/day while at station 5 the highest value was 1.82. This is a 30 fold decrease in production at the hot water site. Huh (1980) found that the standing crop of phytoplankton at intake waters of the cooling system was generally greater than that of the discharge for the most sample period. He attributed this decrease as possibly due to metabolic impairment and/or physical breakdown of the plankton by the thermal and mechanical stresses in the cooling systems. Cairns (1956) observed that the growth of diatoms and blue green alga are affected by increases in temperature. Diatom population tend to reduce with increase in temperature where as blue green algal population tend to peak at temperatures of 40 ^{o}C. At the hot water site the dominant microalgae are the thermophillic blue greens of Trichodesmium spp. Another interesting feature is the presence of blue green macroalgae such as Oscillatoria limosa and Lyngbia

majuscula found attached to the boulders at the hot water discharge point. Ahmed et al.(1992) observed similar blue green algal mats at the heated effluent discharge zone of Madras Atomic Power Station.

Primary production at hot water effluent site exhibited hetrotrophy as reflected by a lower net productivity to respiration ratio, while the other stations were autotrophic. The respiration rate at the hot water effluent site is 93% greater than the control site (Station 5). Thom et al.(1994) also noticed a 57% increase in respiration at a graveled plot at Chapman Cove. Gessner (1970) observed that with a rise in temperature the amount of dissolved oxygen decreases causing secondary modification in the respiration rate. Changes in temperature can further lead to alterations in the dissociation ratio of carbonic acid, which can subsequently affect photosynthesis. It is therefore clear that an increase in temperature coupled with decrease in dissolved oxygen increases respiration rate leading to low net productivity. Further, the low oxygen values observed at the hot water and waste water effluent sites may be due to the increased decomposition promoted by the addition of significant volumes of heated effluent as observed by Nugant (1970).

Salinity and pH does not show any significant relationship between stations. Salinity value indicates that at higher temper-

ature there is a gradual increase in salinity in the hot effluent site. But this increase in salinity is not high, the variation being only on the order of 1 $^{o}/_{oo}$. Zieman (1970) also noticed minimal variations in salinity at Turkey Point, Florida.

The relationship between pH, temperature and dissolved oxygen is reported by Sverdrup (1955). High temperature in association with low oxygen results in a gradual increase in pH. Similar increase in pH at hot water site was observed in the present study.

The importance of nutrients in primary productions is well documented (Harvey, 1934; Qasim et al., 1972; Wafer et al. 1985); Wafer et al., 1986; Gopinathan and Rodrigo, 1991). At the hot water effluent site, the values of phosphate and nitrate were comparatively lower than the other stations. But Nugant (1970) did not observe any influence by hot water effluent on the levels of inorganic phosphate in the water around Turkey Point, Florida.

At elevated water temperature there is a supersaturation of nitrogen which leads to fish mortality (Ebel et al., 1971). Fish mortality from nitrogen embolism due to elevated temperatures of power plant discharges have been reported (Clark and Brownell, 1973). However, elevated values of nitrate was not observed at the hot water effluent site of TTPS. Fish mortality in vicinity of the thermal power station has also not been reported from

Tuticorin Bay. It is difficult to explain why elevated nitrogen values are not observed at hot water effluent site although the sampling was carried out at the core of the thermal plume. The marine ecosystem is so complex that it is difficult to measure the totality of ecological effects caused by any persistent large scale increase in temperature.

The hydrographical parameters did not show significant variation between seasons except for values of silicate. Sankaranarayanan and Qasim (1969) reported an inverse relationship between silicate and salinity. Silicate value was high during the postmonsoon months at all stations in the present study coinciding with low values in salinity. High values of nutrients were not observed at station 2 although there is discharge of waste water at this site. Net productivity at this station was not influenced by nutrients probably due to the high turbid waters inhibiting primary productivity of this area. Nutrients played an important role in net production at the intermediate stations and at the control station.

From the above discussion on the hydrography of Tuticorin Bay it is evident that thermal pollution results in increased water temperature, low dissolved oxygen and low net production. At the waste water effluent site, turbidity is the most limiting factor of primary production. The significant differences in the

variation of hydrographical parameters also indicate that there is a profound influence by the hot water and waste water effluents on the coastal ecosystem of Tuticorin. Hydrography does not seem to be significantly affected by climatic factors such as rainfall, wind and freshwater runoff.

The Ministry of Environment and Forests, Government of India has declared Gulf of Mannar which includes Tuticorin Bay as Biosphere Reserve in April 1988 to preserve genetic diversity of this marine ecosystem. It also gave directives to the state of Tamil Nadu to take steps for the conservation of the flora and fauna in this area. The present investigation on the hydrography of the area reveals that dumping of thermal and waste effluents into Tuticorin Bay has caused considerable damage to this fragile ecosystem.

Chapter 2

Physiology of Selected Seaweeds

INTRODUCTION

Seaweeds constitute an important renewable marine resource that grow in the shallow waters wherever suitable substrate are available. In India, seaweeds are abundant along the southeastern and northwestern coast. There are more than 600 known species of seaweeds in India of which 60 are commercially important. Seaweeds are used as food, fodder and fertilizer. They are extensively used in various industries like confectionery, textile, paint, cosmetics, paper, dairy and pharmaceuticals. Agar-agar and algin are the two main phyco-colloids obtained from seaweeds. Agar-agar is a gelatinous carbohydrate present in the cell walls of some red algae. It is employed as solidifying agent in bacteriological culture media. Algin is the main polysaccharide occurring in the cell walls of brown algae.

Seaweeds are ideal indicators of pollution because they are sessile, easily accessible and sensitive to environment factors. Since seaweeds do not have a root, stem and leaf, the entire body known as thallus absorb the nutrients from the surrounding water for its survival. Any pollutant or toxic elements present in seawater gets accumulated to critical or lethal levels. Seaweeds being primary producers contribute to the sustenance of higher trophic levels.

The impact of pollution can be measured by understanding the relationship between metabolic rates of organisms on one side and the variations in dissociation, solubility and stability of pollutants on the other. Therefore it is necessary to determine the organisms that may serve as indicators of pollution and to understand their biology and ecology, particularly with reference to their physiological tolerances under stress conditions.

In this chapter an attempt is made to study the impact of thermal effluents discharged from Tuticorin Thermal Power Station (TTPS) on the physiological processes of selected seaweeds. The impact of environmental variables on physiology of seaweeds were compared between polluted and control sites. The physiological parameters studied were :

i) changes in net productivity and chlorophyll content and
ii) variations in protein, carbohydrate and lipid of seaweeds.

Productivity of an ecosystem depends on the amount of organic matter produced by plants through photosynthesis. The production by benthic seaweeds may approach 10% of that by phytoplankton (Ryther, 1963). Mann (1973) summarized the productivity of seaweeds and Littler (1973) reported the productivity of Hawaiian reef Coralinaceae. These reports suggest that coastal and reef algal communities rank among the highest

primary producers. The photosynthetic responses of seaweeds are affected by the availability of light (Tolentino and Trono, 1995).

In tropical environments, the production and survival of seaweeds are to a large extent controlled by water temperature. Biebl (1962) showed that the thermal death point of submerged algae in Puerto Rico is 32-35 ^{o}C which is only 4-6 ^{o}C higher than the average summer maximum of 28 ^{o}C. Hohman and Tsuda (1973) found that above 28 ^{o}C photosynthetic rates of Caulerpa reacemosa decreased continuously, and that increasing the temperature from 28 to 30 ^{o}C doubled the respiration rate. A variety of tropical benthic macroalgae tested in south Florida had abrupt thermal limits between 31 and 33 ^{o}C (Bader et al., 1972). The effects of thermal effluents on algal microcosms in tropical estuaries was studied by Thorhaug (1977). Marine blue-green algae replaced seagreasses, green and red algae in thermally elevated area (Roessler and Zieman, 1969; Ahmed et al., 1992). Direct effects of thermal effluents on algal thalli include frond hardening, bleaching or darkening, plasmolysis and cellular disruption (Vadas, 1979). Devinny (1980) and van Tine (1981) observed decreased species numbers and density of plants in thermal plume waters.

Nutrient limitation has a pronounced effect on production and growth of seaweeds. Elevated ammonia levels depressed growth

rates of Cladophora vagabunda and Gracilaria tikwahiae in areas associated with eutrophication (Peckol and rivers, 1995). Photosynthetic and respiratory performance of green, red and brown algae were influenced by the levels of nutrients in the water (Paalme, 1995).

Kumar and Mahadevan (1993) studied algal species diversity as an index of pollution in Tuticorin marine waters. Ganesan and Kumar (1994) observed seasonal variation in productivity of Gracilaria corticata, Sargassum wightii and Padina gymnospora of the Gulf of Mannar. Similar seasonal variations in photosynthesis of benthic macroalgae of Coliumo Bay, Chile was observed by Alveal et al.(1986). The reef community composed of many macroalgae at Kavaratti Atoll, Lakshadweep produce more organic matter in a day than it consumes in 24 hours (Qasim, et al., 1972). Kaladharan and Kandan (1997) observed that seaweeds distributed in 3-4 meter depth can contribute to primary production than those distributed in shallow waters.

Chlorophyll and carotenoids are the two major pigments that play important role in photosynthesis. Jayasankar and Ramalingam (1993) analysed the photosynthetic pigments of 30 species of marine algae collected from different localities of Mandapam, Tamil Nadu Coast. Seasonal variation in chlorophyll content of seaweeds of Gulf of Mannar was reported by Ganesan and Kannan (1994). Behairy and El-Sayed (1983) estimated chlorophyll 'a' and

'c' of five species of brown algae from Jeddah Coast, Saudi Arabia. Light intensity regulates choloroplast structure and pigment composition in the red algae Griffithsia pacifera (Waaland et al., 1974).

The biochemical composition of seaweeds has received more attention than that for productivity and chlorophyll contents. Vijayaraghavan et al.(1980) studied the seasonal variation in biochemical compositions of seaweeds from Goa Coast and by Dhargalkar et al.(1980) along the Maharastra Coast. Kaliaperumal et al.(1994) described the protein, carbohydrate and lipid of 28 marine seaweeds from Lakshadweep Islands. The algae belonging to Chlorohyceae and Rodhophyceae were rich in protein and carbohydrate compared to Phaeophyceae (Kumar, 1993). Ganesan and Kumar (1994) studied seasonal variation in the biochemical constituents of economic seaweeds of Gulf of Mannar. Jayasankar (1993) analysed the biochemical composition of Sargassum wightii with reference to alginic acid content. Twenty three species of green algae belonging to 12 genera from Mandapam were analysed for protein, carbohydrate and lipid by Jayasankar et al.(1990). Biochemical studies of different groups of algae from Cape Comorin and Kovalam was reported by Sobha et al.(1990).

The seasonal variability of Hypnea musciformis, Gelidiella acerosa and Sargassum vulgare from the southeast coast of Jamaica was reported by Prasad and Potluri (1992). Investigations on

seasonal changes in biochemistry of seaweeds from Karachi Coast has been reported (Qari, 1988; Qari and Qasim, 1993; Qari and Siddiqui, 1993). Behairy and El-Sayed (1983) reported biochemical composition of marine brown algae of Jeddah Coast, Saudi Arabia.

Protein, peptides and free amino acids of marine algae has been reviewed by Kaliaperumal et al.(1987). Dhargalkar et al.(1980)estimated protein content of 43 species of marine algae and found that protein level varied from 10-33%. Seasonal variation in protein content of Gracilaria verrucosa from the Aegean Coast of Izmir, Turkey is reported (Ilyas and Sukan, 1994). Protein fractions of 3 species of seaweeds studied by Ochiai et al.(1987) were rich in aspartic and glutamic acid, glycine and alanine but poor in methionine, tyrosine and histidine. Protein content of 15 species of benthic algae from Bahrain was determined using the dye-binding technique (Abbas et al., 1992). Proximate composition of wild and cultured strains of the red algae Palmaria palmata was studied by Mishra et al.(1993). Among the seaweeds studied by Parekh and Chauhan (1987), Padina gymnospora and Laurencia cruciata showed high total lipid content.

The foregoing literature review indicates that there are very few works on productivity and chlorophyll content of marine algae of Indian Seas. Studies on physiological and biological aspects of seaweeds in thermal effluent areas are totally

lacking. In tropical areas, seaweeds and other organisms live only a few degree below their upper lethal temperatures. Therefore it is important that close monitoring of environments be made to understand the changes that occur in the growth and survival of marine seaweeds.

MATERIALS AND METHODS

Regular sampling of seaweeds in the study area was carried out from October 1987 to September 1989. The polluted and control stations were fixed as described in Chapter 1.

The three species of seaweeds selected for study were those found at Polluted and controll stations in the study area throughout the year, so they were selected.

1. Division : Rodhophyta
   Class : Rodhophyceae
   Order : Gigartinales
   Family : Gracilariaceae
   Species : Gracilaria verrucosa

They are red to purple, brownish, translucent, 12 to 20 cms high. Fronds are irregularly branched, firm, fleshy and cartilaginous. It is used as raw material for agar manufacture. This is one of the several edible species of alagae found in shallow intertidal areas on muddy substrate, attached as epiphytes on seagrasses and are found in diverse ecological

conditions. It has been reported or described in conditions of a wide range of temperature and is distributed widely in the earth's seas.

2. Division : Chlorophyta
Class : Chlorophyceae
Order : Ulvales
Family : Ulvaceae
Species : Enteromorpha compressa

Plants are light or bright green in colour and adult plants are more or less compressed, dilated towards the apex, tapering below and with several branches. Fronds vary in lengths from 1.5 to 6.5 cms. It grows attached to dead molluscan shells and exposed rocks in the intertidal area. This species is also common in rivers flowing into the sea. They are capable of existing in a rather wide range of salinity often ascending some distance into estuaries, especially when there is some pollution activities.

3. Division : Chlorophyta
Class : Chlorophyceae
Order : Cladophorales
Family : Cladophoraceae
Species : Chaetomorpha linum

C.linum is green to yellowish green in colour and composed of unbranched filaments, twisting together to form clumps or tangles. It is eaten as salad and cooked with fish, meat etc. It grows on rocks and are often seen enmeshed with other algae.

Productivity of seaweeds: The method described by Qasim et al. (1972) was followed for the study. Freshly collected seaweeds

were carefully washed with filtered seawater and acclimatized for 24 hours. Each species weighing 2 gm wet weight was kept in glass bottles of 300 ml capacity. These bottles were filled with filtered seawater and closed tightly while immersed in a bucket of seawater to prevent entry of atmospheric oxygen. The bottles painted black, covered in aluminium foil and further enclosed by black rexine was used as dark bottles. A sample of seawater was fixed with Winkler A and B which was used as initial concentration of oxygen. The bottles were then suspended in the intertidal area approximately 20 cm from the surface. In each experiment triplicate sets were used and incubated for a period of 3 hours. At the end of the exposure, the water in bottles were carefully siphoned off and fixed. A set of controls containing only seawater was also exposed in light and dark bottles. Increase and decrease in the light and dark bottles from the initial value were taken as photosynthesis and respiration respectively. Winkler determinations were carried out to calculate the oxygen produced and consumed. These values were then converted for carbon equivalents employing the factor 0.536/1.25. Results were expressed in gC/gm/day.

Chlorophyll : Chlorophyll 'a', 'b' and 'c' are estimated in the three species of seaweeds as described by Jaffery and Humphery (1975).

Seaweeds collected from the sampling stations are washed with seawater. They were then washed with freshwater and rinsed

with distilled water. One gm of weighed seaweed was ground in mortar and pestle with 10 ml of 90% acetone solution and 1 drop of magnesium carbonate solution. The solution was centrifuged at 5000 rpm for 5 minutes. The supernatent was collected and residue re-extracted with 10 ml of 90% acetone. The supernatent was then made upto 25 ml with 90% acetone. The extinction was measured at 664, 647 and 630 nm for chlorophyll 'a','b' and 'c' respectively.

The amount of chlorophyll in the samples was calculated using the following equations:

$$\text{Chlorophyll 'a' (Ca)} = 11.6\ D_{664} - 1.31\ D_{647} - 0.14\ D_{630}$$

$$\text{Chlorophyll 'b' (Cb)} = 20.7\ D_{647} - 4.34\ D_{664} - 4.42\ D_{630}$$

$$\text{Chlorophyll 'c' (Cc)} = 55.0\ D_{630} - 4.60\ D_{664} - 16.30\ D_{647}$$

The results were expressed in ug/gm.

Biochemical composition: Protein, carbohydrate and lipid are the three biochemical parameters that were determined. Seaweeds were collected and debris removed using ambient seawater, then washed again with a jet of fresh water and finally washed with distilled water. These seaweeds were dried in over at 60-70 ^{o}C for 24 hours and dried material was ground to a fine powder and sieved. This powdered and sieved seaweeds were taken for estimation of protein, carbohydrate and lipid.

Protein: The protein content was analysed by the revised method of Hartree (1972). One gram of seaweed powder was soaked in 10 ml 1% sodium hydroxide and warmed in a waterbath at 60 ^{o}C for 3 hours and then cooled and centrifuged at 3000 rpm for 5 minutes. To 0.1 ml of supernatent solution is taken into a test tube and made upto 1 ml with 0.9 ml of sodium hydroxide solution. To this 5 ml of alkaline copper reagent is added, which is prepared by mixing 50 ml of reagent A (2 gm of sodium bicarbonate in 100 ml of 0.1N sodium hydroxide solution) and 1 ml of reagent B (0.5 gm of copper sulphate in 100 ml of 1% sodium potassium tartrate solution). After 10 minutes, 0.5 ml of 1N Folin's reagent is added and kept for 30 minutes. The absorbance was measured at 670 nm after 30 minutes. The absorbance of the sample was corrected with a reagent blank. Results are expressed in percentage of protein/gm dry weight.

Carbohydrate: The carbohydrate content was analysed by phenol-sulphuric acid method of Dubois et al.(1956). One gram of seaweed powder soaked overnight in 10 ml of 1N sulphuric acid and was kept in waterbath at 100 ^{o}C for 12 hours and centrifuged at 3000 rpm for 5 minutes. The supernatent was made to 50 ml using 1N sulphuric acid and stirred well. To 0.1 ml of this solution, 0.9 ml of 1N sulphuric acid and 1 ml of 5% phenol solution was added followed by 5 ml of concentrated sulphuric acid, agitated and after 30 minutes absorbance was measured at 470 nm. The absorbance of the sample was corrected with a reagent blank.

Results are expressed in percentage carbohydrate/gm dry weight.

Lipid: The lipid was extracted by the method of Folch et al., 1957 and estimated by sulphovanillin method (Barnes et al., 1973). To 0.1 gm of seaweed powder, 10 ml of chloroform and methanol mixture (2:1) is added and homogenized and centrifuged at 3000 rpm for 10 minutes. The solution was filtered and made upto 25 ml with chloroform and methanol mixture and mixed well. One ml of the mixture was taken in a test tube and evaporated at 50-60 ^{o}C in a waterbath and then 1 ml of concentrated sulphuric acid was added to the residue and mixed. The test tube was plugged with non absorbent cotton and kept in a water bath at 100 ^{o}C for 10 minutes. It was then cooled rapidly and to 0.2 ml of aliquot, 5 ml of vanillin reagent was added (200 ml orthophosphoric acid + 50 ml water + 0.5 gm vanillin powder) and mixed thoroughly. After 1 hour absorbance was measured at 520 nm. The absorbance of the sample was corrected with a reagent blank. Results are expressed in percentage lipid/gm dry weight.

RESULTS

Seaweeds could not be collected from station 1 (hot water effluent site) as there is no vegetation in this area. The average values of net production and respiration of seaweeds are presented in Table 1. Net production at station 2 was

comparatively lower than the other stations for all the species studied. A similar trend is noticed in the seasonal averages of chlorophyll 'a','b' and 'c' (Table 2). At station 2 higher values of chlorophyll is observed for Chaetomorpha linum followed by Enteromorpha compressa and Gracilaria verrucosa. This variation is observed only in the case of station 2 were as in the other stations the chlorophyll content is more or less uniform in E.compressa and C.linum. The variation in protein and carbohydrate at station 2 when compared to that of station 5 is high in the increasing order of E.compressa > C.linum > G.verrucosa (Table 3). The variations in lipid content is however in the order of G.verrucosa > E.compressa > C.linum. At control station the protein is maximum in G.verrucosa in contrast to others and the situation is reversed in the case of station 2 (waste water effluent site).

A two-way analysis of variance between stations and seasons for physiology of seaweeds indicate that all parameters are significant at either 5% or 1% level (Table 4). Correlation of hydrographical parameters on net productivity of different species of seaweeds is presented in Table 5. Water temperature has a negative correlation with net production of E.compressa and G.verrucosa. Physical parameters of seawater such as salinity, dissolved oxygen and pH are related to productivity at stations 3 and 5. Among nutrients, phosphate has a positive influence on production. Except for station 5, turbidity has a negative

influence on production. Physical parameters in general does not affect the chlorophyll content of seaweeds (Table 6). Nutrients is positively correlated with changes in chlorophyll 'a' content. Turbidity has a negative effect on chlorophyll 'a' at station 2.

Correlation of hydrographical parameters on biochemical constituents are given in Table 7. The physical parameters has no definite influence on biochemistry of seaweeds. A wide spread dominance of nutrients on biochemical parameter is clearly evident at all stations. Turbidity controls the protein and carbohydrate variations at station 2 and 3.

The bimonthly net production values of G.verrucosa and E.compressa are presented in Fig. 1A and 1B. The production values show an increasing trend from stations 2 to 5 with peaks during premonsoon months of June and August. C.linum (Fig.2A) showed peaks during the postmonsoon months (February-April). An opposite trend is observed for chlorophyll 'a' with peak values during February-April for G.verrucosa (Fig.2B) and E.compressa (Fig.3A). The variations in protein and carbohydrate contents show minor peaks during postmonsoon months (Fig.4A,B) while lipid content is high during monsoon (Fig.5).

Table 1 : Seasonal averages of net production and respiration of seaweeds at stations 2 to 5.

Parameter	Season	Stations			
		2	3	4	5
G.verrucosa					
Net production (gC/gm/day)	Premonsoon	1.4	2.6	3.0	3.9
	Monsoon	1.0	2.1	2.6	3.1
	Postmonsoon	1.2	2.2	2.8	3.2
Respiration (gC/gm/day)	Premonsoon	3.1	1.6	1.3	1.0
	Monsoon	2.9	1.5	1.1	0.7
	Postmonsoon	3.0	1.5	1.3	0.8
E. compressa					
Net production (gC/gm/day)	Premonsoon	1.6	2.0	2.5	2.6
	Monsoon	1.0	1.6	2.3	2.2
	Postmonsoon	1.2	1.8	2.3	2.4
Respiration (gC/gm/day)	Premonsoon	2.9	1.7	1.4	1.0
	Monsoon	2.3	1.3	1.0	0.9
	Postmonsoon	2.4	1.5	1.3	0.9
C. linum					
Net production (gC/gm/day)	Premonsoon	1.2	1.4	2.1	2.3
	Monsoon	1.1	1.3	1.9	2.2
	Postmonsoon	1.4	1.8	2.3	2.9
Respiration (gC/gm/day)	Premonsoon	2.6	2.2	1.9	0.9
	Monsoon	2.8	2.3	2.0	1.0
	Postmonsoon	3.0	2.5	2.0	0.4

Table 2 : Seasonal averages of Chlorophyll `a', `b' and `c' of seaweeds at station 2 to 5.

Parameter	Season	Station 2	3	4	5
G.verrucosa					
Chlorophyll `a' (µg/gm)	Premonsoon	0.2	0.2	0.4	0.3
	Monsoon	0.1	0.2	0.3	0.3
	Postmonsoon	0.2	0.3	0.6	0.6
Chlorophyll `b' (µg/gm)	Premonsoon	0.2	0.6	1.0	1.0
	Monsoon	0.2	0.5	0.9	0.9
	Postmonsoon	0.3	0.6	1.2	1.2
Chlorophyll `c' (µg/gm)	Premonsoon	0.2	0.4	0.9	0.9
	Monsoon	0.1	0.3	0.8	0.9
	Postmonsoon	0.2	0.5	1.0	1.1
E.compressa					
Chlorophyll `a' (µg/gm)	Premonsoon	0.8	1.3	1.9	1.8
	Monsoon	0.8	1.1	1.3	1.4
	Postmonsoon	0.9	1.3	2.2	2.2
Chlorophyll `b' (µg/gm)	Premonsoon	0.8	1.4	2.4	2.4
	Monsoon	0.7	1.1	1.6	1.6
	Postmonsoon	0.9	2.1	3.4	3.5
Chlorophyll `c' (µg/gm)	Premonsoon	0.6	1.2	2.3	2.2
	Monsoon	0.5	1.0	1.4	1.5
	Postmonsoon	0.8	2.1	3.2	3.3
C.linum					
Chlorophyll `a' (µg/gm)	Premonsoon	1.2	1.2	1.8	1.8
	Monsoon	0.9	1.0	1.4	1.5
	Postmonsoon	1.1	1.2	1.6	1.6
Chlorophyll `b' (µg/gm)	Premonsoon	1.3	2.0	2.8	2.8
	Monsoon	1.0	1.3	2.2	2.2
	Postmonsoon	1.2	2.0	2.5	2.5
Chlorophyll `c' (µg/gm)	Premonsoon	1.9	2.3	2.8	2.9
	Monsoon	1.1	1.8	2.2	2.4
	Postmonsoon	1.3	2.0	2.4	2.5

Table 3 : Seasonal averages of protein, carbohydrate and lipid of seaweeds at station 2 to 5.

Parameter	Season	Station 2	3	4	5
G. verrucosa					
Protein (%)	Premonsoon	5.2	12.2	17.1	17.1
	Monsoon	4.2	10.7	16.4	15.3
	Postmonsoon	5.6	12.6	18.1	18.4
Carbohydrate (%)	Premonsoon	17.7	24.2	37.2	37.2
	Monsoon	18.7	25.8	36.8	37.1
	Postmonsoon	21.5	30.9	44.7	45.5
Lipid (%)	Premonsoon	2.0	2.9	3.8	5.5
	Monsoon	1.4	2.6	3.4	4.8
	Postmonsoon	3.5	4.3	5.8	7.7
E. compressa					
Protein (%)	Premonsoon	7.2	9.1	11.5	10.6
	Monsoon	7.4	7.8	10.4	11.4
	Postmonsoon	9.1	9.6	13.5	13.5
Carbohydrate (%)	Premonsoon	14.8	20.8	21.7	21.8
	Monsoon	20.0	25.9	28.6	28.7
	Postmonsoon	16.3	24.9	24.0	24.0
Lipid (%)	Premonsoon	3.1	6.9	9.9	9.9
	Monsoon	4.3	7.7	10.9	11.7
	Postmonsoon	3.7	7.3	10.2	10.7
C. linum					
Protein (%)	Premonsoon	5.7	8.9	12.2	12.6
	Monsoon	4.6	8.1	10.6	10.9
	Postmonsoon	6.2	9.7	13.2	13.4
Carbohydrate (%)	Premonsoon	14.8	18.8	28.5	30.1
	Monsoon	16.0	18.7	27.3	29.3
	Postmonsoon	16.9	20.1	30.3	31.2
Lipid (%)	Premonsoon	1.4	6.2	11.0	11.2
	Monsoon	1.2	5.7	10.3	10.5
	Postmonsoon	2.6	8.2	12.4	12.8

Table 4 : A two-way ANOVA between stations and seasons for physiology of different species of seaweeds.

Parameter	Source	df	SS	MSS	F	P
Net production						
G.verrucosa	Treatment	3	10.52	3.51	47.29	P<0.01
	Replicate	2	0.90	0.41	6.68	P<0.05
	Error	6	0.45	0.07		
E.compressa	Treatment	3	2.60	0.87	111.26	P<0.01
	Replicate	2	0.33	0.16	21.00	P<0.01
	Error	6	0.05	0.01		
C.linum	Treatment	3	2.83	0.94	82.80	P<0.01
	Replicate	2	0.49	0.24	21.29	P<0.01
	Error	6	0.07	0.01		
Chlorophyll `a´						
G.verrucosa	Treatment	3	0.15	0.05	8.95	P<0.05
	Replicate	2	0.09	0.04	7.80	P<0.05
	Error	6	0.03	0.01		
E.compressa	Treatment	3	2.00	0.69	15.02	P<0.01
	Replicate	2	0.51	0.25	5.70	P<0.05
	Error	6	0.27	0.04		
C.linum	Treatment	3	2.49	0.83	129.74	P<0.01
	Replicate	2	0.76	0.38	59.61	P<0.01
	Error	6	0.04	0.01		
G.verrucosa						
Protein	Treatment	3	294.62	98.21	588.37	P<0.01
	Replicate	2	8.35	4.18	25.02	P<0.01
	Error	6	1.00	0.17		
Carbohydrate	Treatment	3	916.71	305.57	159.04	P<0.01
	Replicate	2	106.81	53.41	27.80	P<0.01
	Error	6	11.53	1.92		
Lipid	Treatment	3	22.61	7.54	103.16	P<0.01
	Replicate	2	11.44	5.72	78.26	P<0.01
	Error	6	0.44	0.07		
E.compressa						
Protein	Treatment	3	37.02	12.34	30.57	P<0.01
	Replicate	2	10.91	5.46	13.52	P<0.01
	Error	6	2.42	0.40		
Carbohydrate	Treatment	3	126.82	42.27	48.48	P<0.01
	Replicate	2	73.23	36.62	41.99	P<0.01
	Error	6	5.23	0.87		
Lipid	Treatment	3	96.23	32.08	645.23	P<0.01
	Replicate	2	2.90	1.45	29.12	P<0.01
	Error	6	6.30	6.05		
C.linum						
Protein	Treatment	3	90.98	30.33	346.66	P<0.01
	Replicate	2	8.80	4.40	50.27	P<0.01
	Error	6	0.53	0.09		
Carbohydrate	Treatment	3	444.54	148.18	418.58	P<0.01
	Replicate	2	7.70	3.85	10.87	P<0.05
	Error	6	2.12	0.35		
Lipid	Treatment	3	190.48	63.49	948.41	P<0.01
	Replicate	2	9.31	4.66	69.55	P<0.01
	Error	6	0.40	0.07		

Table 5 : Correlation of hydrographical parameters on net productivity of different species of seaweeds.

Parameters	Net productivity		
	G.verrucosa	E.compressa	C.linum
Station 2			
Water temperature	-0.38	-0.45*	0.10
Salinity	0.24	0.25	-0.04
Dissolved oxygen	0.20	0.23	-0.06
pH	-0.24	-0.24	-0.16
Phosphate	0.61*	0.64*	0.26
Nitrate	0.11	0.17	0.36
Silicate	0.17	0.09	0.59*
Turbidity	-0.76*	-0.70*	-0.26
Station 3			
Water temp.	-0.30	-0.22	0.16
Salinity	0.43*	0.39	0.12
Diss.oxygen	-0.30	-0.24	0.01
pH	-0.46*	-0.39	0.09
Phosphate	0.37	0.51*	0.34
Nitrate	0.18	0.37	0.28
Silicate	-0.03	0.28	0.52*
Turbidity	-0.42*	-0.45*	0.13
Station 5			
Water temp.	-0.18	-0.07	0.17
Salinity	0.59*	0.52*	-0.17
Diss.oxygen	-0.39	-0.46*	-0.08
pH	-0.37	-0.17	0.34
Phosphate	0.17	0.09	-0.31
Nitrate	0.14	0.14	0.04
Silicate	-0.04	0.22	0.73*
Turbidity	-0.17	-0.29	-0.11

* indicates significant correlation

Table 6 : Correlation of hydrographical parameters on chlorophyll `a´ of different species of seaweeds.

Parameters	Chlorophyll `a´		
	G.verrucosa	E.compressa	C.linum
Station 2			
Water temperature	0.71*	-0.07	-0.34
Salinity	0.01	-0.05	0.21
Dissolved oxygen	0.14	0.01	0.21
pH	-0.15	-0.25	-0.14
Phosphate	0.41*	0.08	0.53*
Nitrate	0.39	0.48*	0.27
Silicate	0.57*	0.52*	0.32
Turbidity	-0.45*	-0.39	-0.49*
Station 3			
Water temperature	0.16	0.10	-0.14
Salinity	0.09	0.06	0.33
Dissolved oxygen	0.04	-0.01	-0.30
pH	0.06	-0.08	-0.39
Phosphate	0.42*	0.45*	0.35
Nitrate	0.45*	0.25	0.17
Silicate	0.78*	0.61*	0.30
Turbidity	-0.21	-0.14	-0.27
Station 5			
Water temperature	0.17	0.07	-0.08
Salinity	-0.30	0.07	0.54*
Dissolved oxygen	-0.01	-0.19	-0.47*
pH	0.39	0.20	-0.15
Phosphate	-0.45*	-0.40	0.07
Nitrate	0.09	0.10	0.14
Silicate	0.70*	0.70*	0.16
Turbidity	-0.18	-0.26	-0.21

* indicates significant correlation

Table 7 : Correlation of hydrographical parameters on biochemical constituents (Protein, Carbohydrate, and Lipid) of different species of seaweeds.

Parameters	G.verrucosa			E.compressa			C.linum		
	P	C	L	P	C	L	P	C	L
Station 2									
Water temp.	0.11	0.25	0.12	0.17	0.40	0.35	-0.14	0.41*	0.18
Salinity	-0.23	-0.22	-0.15	-0.33	-0.10	-0.12	0.05	-0.32	-0.18
Diss.oxygen	-0.04	-0.01	-0.06	0.04	-0.34	-0.21	0.29	-0.10	0.06
pH	-0.10	-0.02	-0.09	-0.03	0.19	0.12	-0.19	0.07	-0.12
Phosphate	0.01	-0.32	0.02	-0.25	-0.45*	-0.45*	0.27	-0.55*	-0.15
Nitrate	0.47*	0.42*	0.51*	0.72*	-0.43*	-0.32	0.48*	0.29	0.53*
Silicate	0.31	0.68*	0.71*	0.85*	-0.39	-0.25	0.66*	0.44*	0.74*
Turbidity	-0.42*	0.31	-0.07	0.15	0.60*	0.64*	-0.28	0.40	0.02
Station 3									
Water temp.	-0.14	0.12	0.22	-0.02	0.19	0.09	0.16	0.15	0.22
Salinity	0.02	-0.10	-0.02	0.09	-0.43*	-0.36	0.13	-0.09	-0.03
Diss.oxygen	0.01	0.04	0.04	-0.09	0.36	0.32	-0.08	0.17	-0.01
pH	-0.17	-0.04	0.07	-0.11	0.33	0.45*	-0.09	0.09	0.03
Phosphate	0.45*	0.36	0.43*	0.59*	-0.34	-0.46*	0.57*	0.31	0.43*
Nitrate	0.61*	0.54*	0.47*	0.58*	-0.05	-0.36	0.56*	0.49*	0.47*
Silicate	0.63*	0.53*	0.76*	0.72*	0.03	-0.30	0.71*	0.65*	0.78*
Turbidity	-0.45*	-0.24	-0.08	-0.43*	0.17	0.36	-0.22	-0.15	-0.14
Station 5									
Water temp.	0.06	0.20	0.22	0.08	-0.17	-0.02	-0.25	0.26	0.15
Salinity	0.13	-0.22	-0.10	-0.31	-0.61*	-0.35	0.25	0.05	0.05
Diss.oxygen	-0.27	-0.10	-0.12	0.06	0.50*	0.35	-0.39	-0.31	-0.12
pH	0.15	0.47*	0.33	0.36	0.04	0.06	0.17	0.20	0.08
Phosphate	-0.43*	-0.33	-0.37	-0.16	0.11	-0.10	-0.30	-0.54*	-0.41*
Nitrate	0.09	0.08	0.04	-0.10	-0.24	-0.17	0.05	-0.08	0.04
Silicate	0.65*	0.68*	0.73*	0.69*	0.02	-0.14	0.56*	0.40	0.68*
Turbidity	-0.27	-0.18	-0.18	-0.16	0.30	0.11	-0.30	-0.20	-0.26

* indicates significant correlation

Fig 1A : Net production of Gracilaria verrucosa at stations 2, 3 and 5

Net production - Gracilaria verrucosa

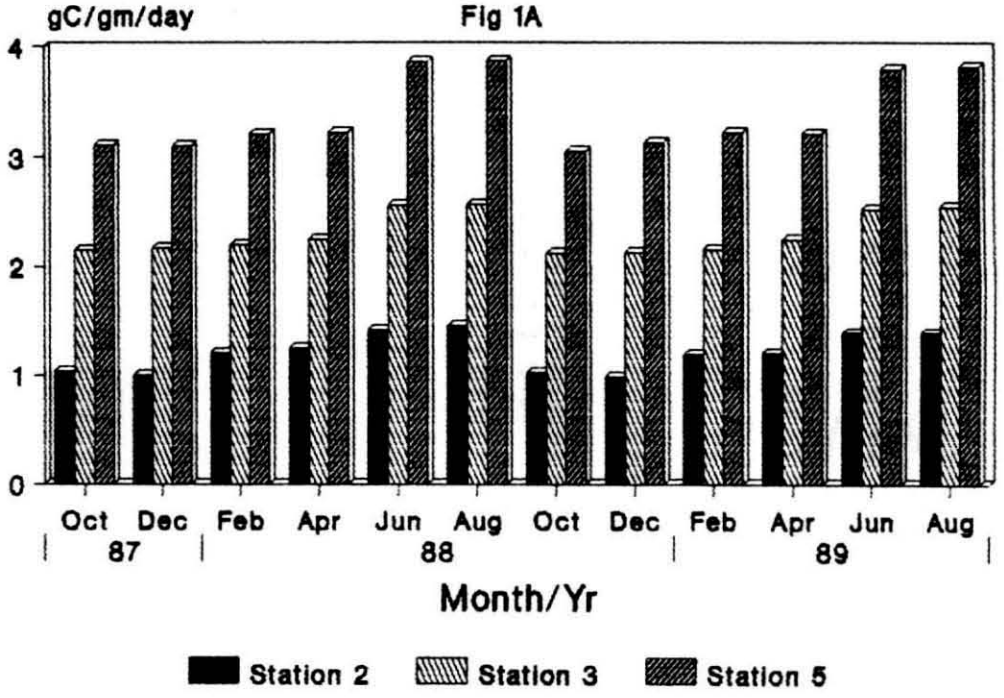


Fig 1B : Net production of Enteromorpha compressa at stations 2, 3 and 5

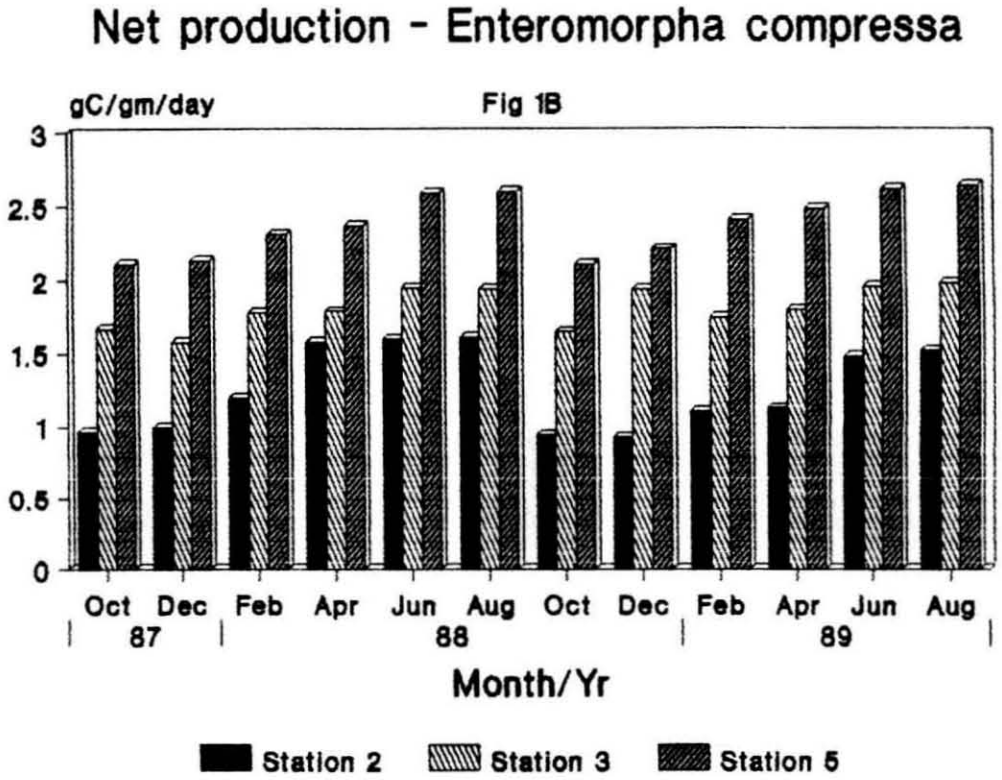

Net production - Enteromorpha compressa
gC/gm/day
Fig 1B
3
2.5
2
1.5
1
0.5
0
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
87
88
89
Month/Yr
Station 2
Station 3
Station 5

Fig 2A : Net production of Chaetomorpha linum at station 2, 3 and 5

Net production - Chaetomorpha linum

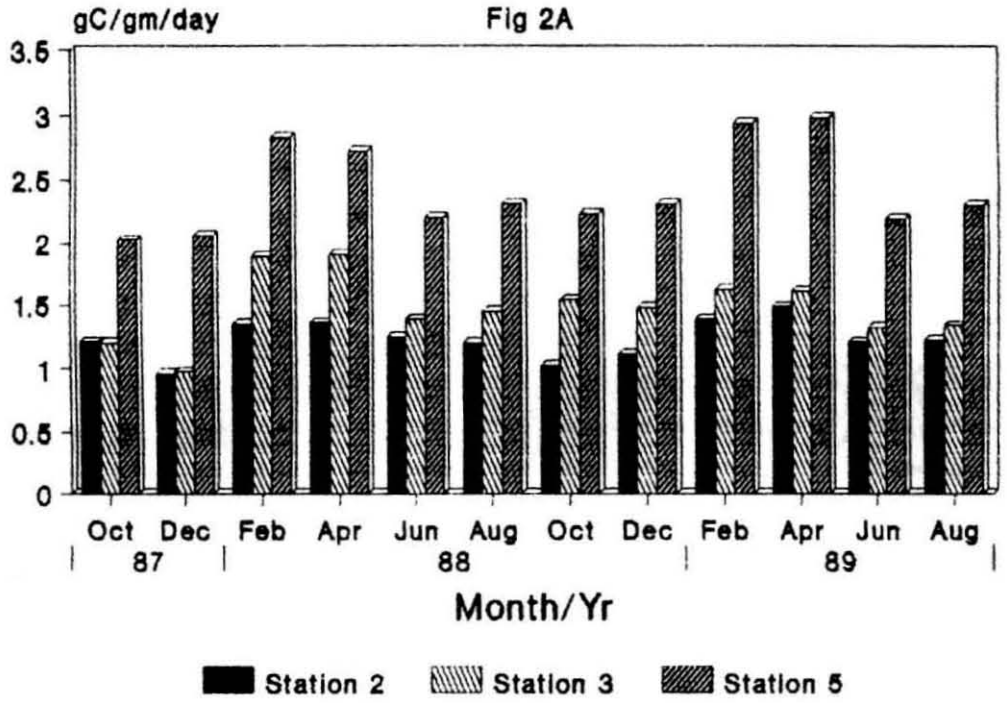


Fig 2B : Chlorophyll 'a' of Gracilaria verrucosa at stations 2, 3 and 5

Chlorophyll a - Gracilaria verrucosa

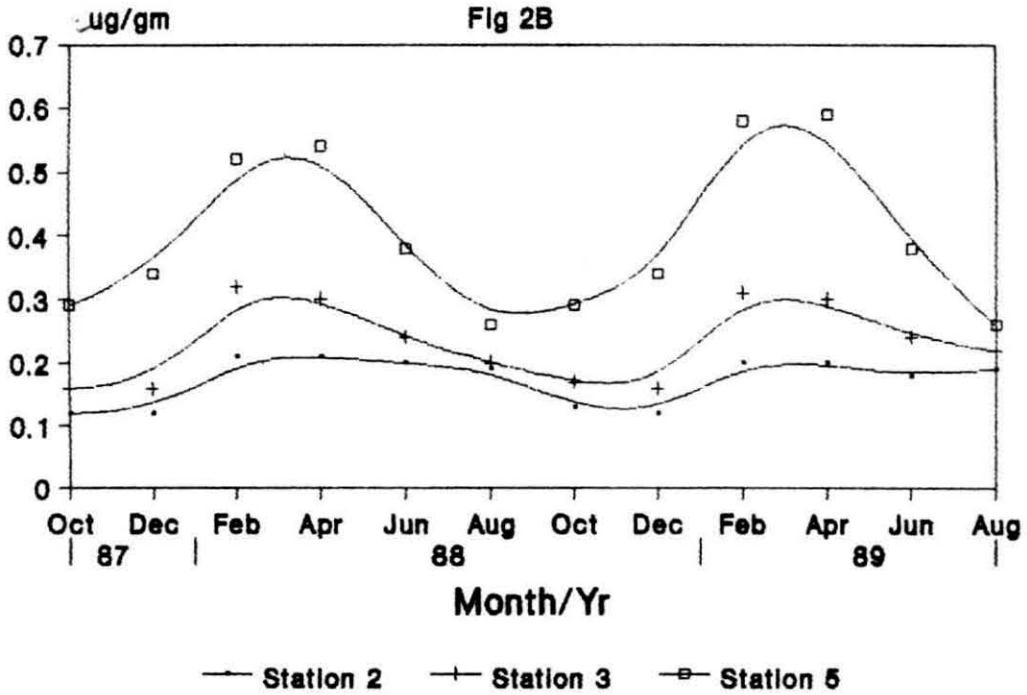


Fig 3A : Chlorophyll 'a' of Enteromorpha compressa at stations 2, 3 and 5.

Chlorophyll a - Enteromorpha compressa

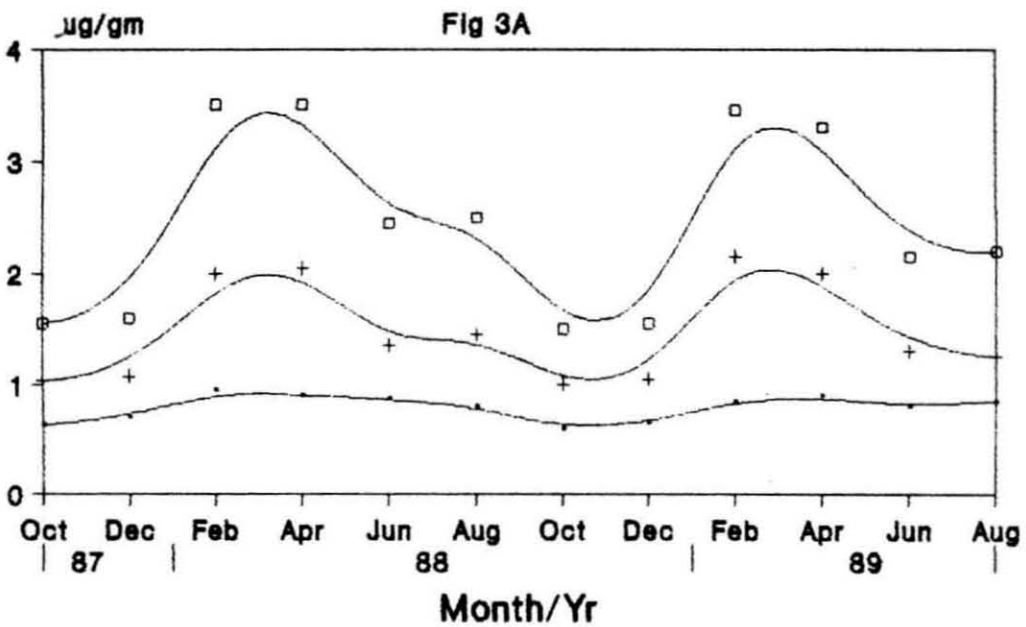


Fig 3B : Chlorophyll 'a' of Chaetomorpha linum at stations 2, 3 and 5

Chlorophyll a - Chaetomorpha linum

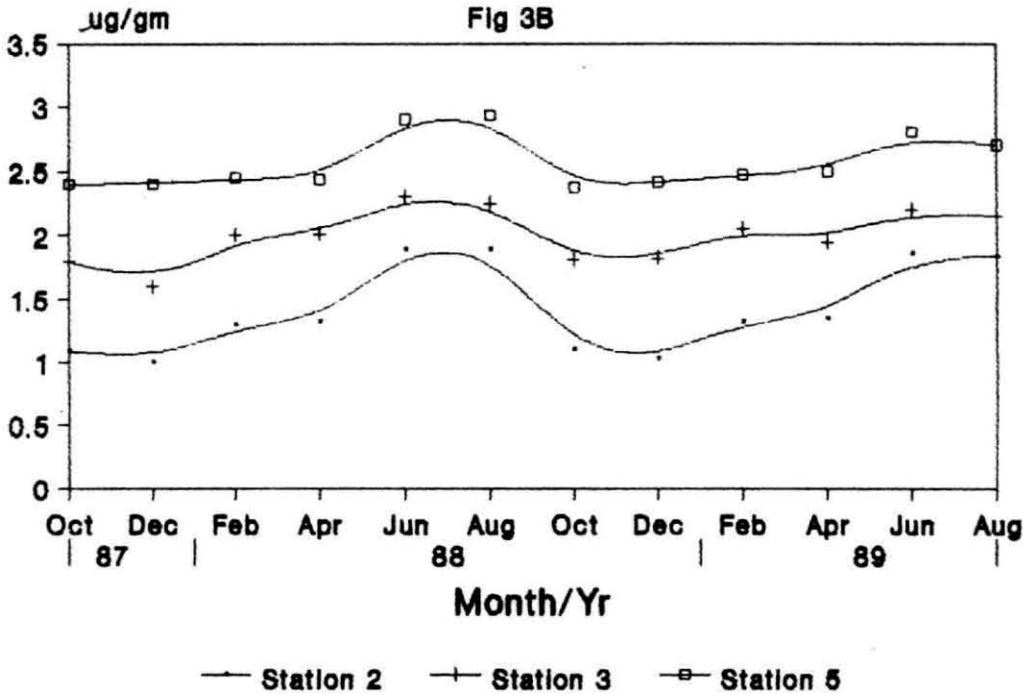


Fig 4A : Protein of Gracilaria verrucosa at station 2, 3 and 5

Protein - Gracilaria verrucosa

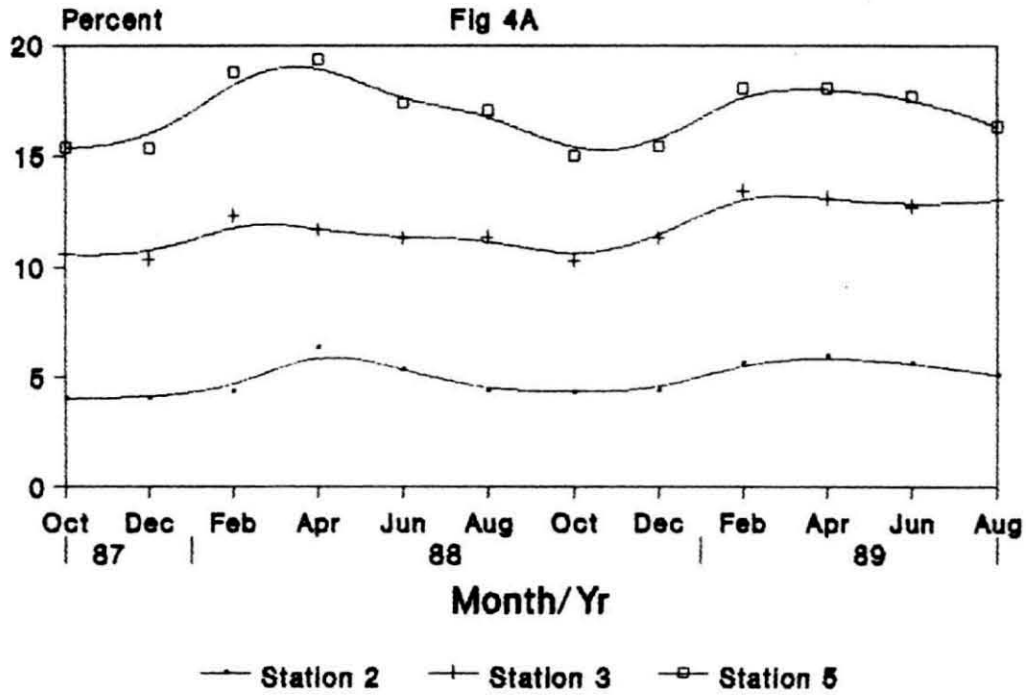


Fig 4B : Carbohydrate of Chaetomorpha linum at stations 2, 3 and 5

Carbohydrate - Chaetomorpha linum

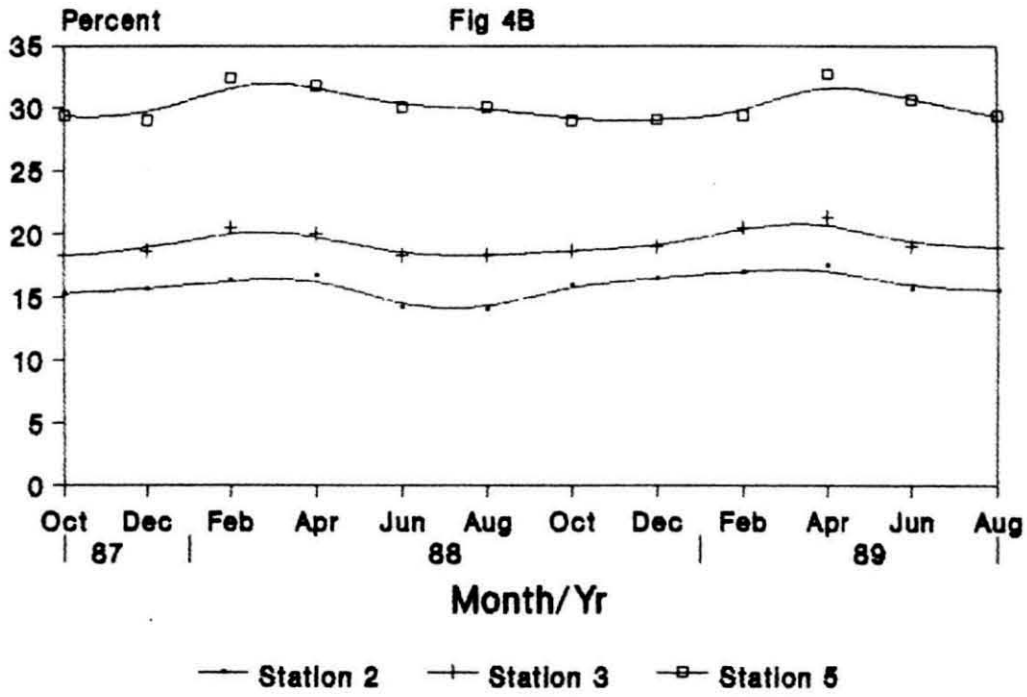
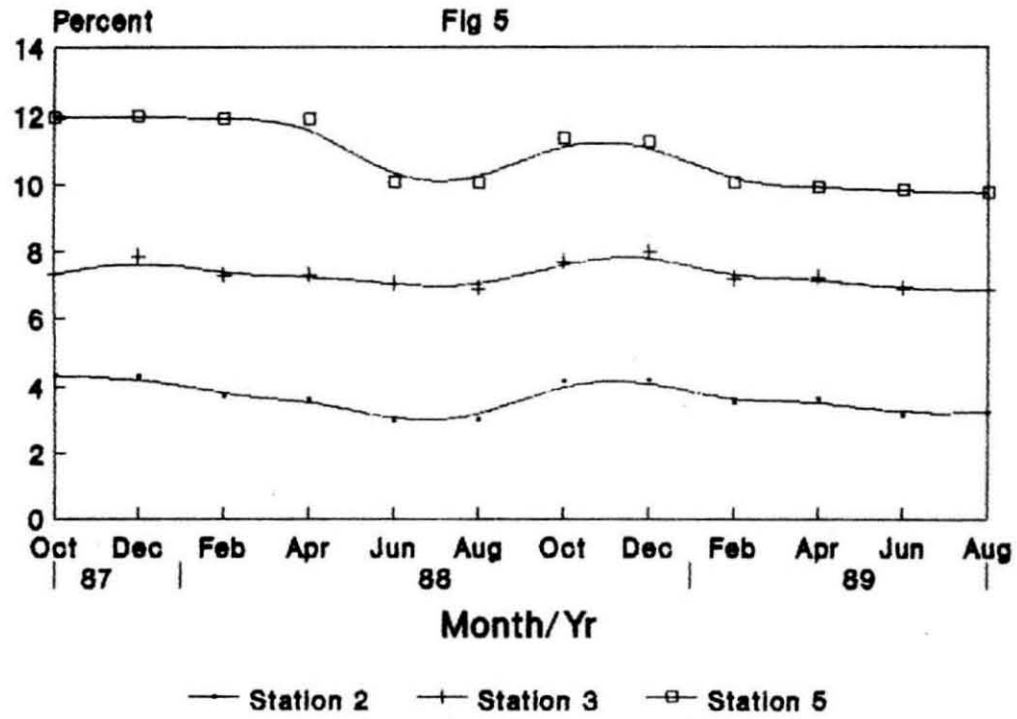


Fig 5 : Lipid of Enteromorpha compressa at stations 2, 3 and 5

Lipid - Enteromorpha compressa



DISCUSSION

It is generally conceded that temperature is the most important single factor governing occurrence and behaviour of life. The introduction of warm water into an ecosystem is known to affect the metabolic rate of organisms. The total absence of seaweed vegetation at station 1 (hot water site) clearly indicate that seaweeds cannot survive at a temperature above 35 ^{o}C. Cairns (1964) defined pollution as "any environmental change which alters the species diversity more than 20% from the empirically determined level for that particular locale". Biebl (1962) found that the thermal death point of submerged algae in Puerto Rico to be 32-35 ^{o}C. A rise in temperature above the maximum upper limit doubles the respiration rate resulting in low P/R ratio (Hohman and Tsuda, 1973). Markowski (1960) reported luxuriant growth of Enteromorpha sp. on settling plates in a thermal discharge stream. At an effluent site in Maine, Arndt (1968) found Enteromorpha abundant replacing Fucus and Ascophyllum.

Roessler (1971) reported that as temperatures increase the red and brown algae are the first eliminated, and at the highest temperature even the green algae may be lost and only the blue-greens survive. The algae observed at station 2 were G.verrucosa, E.compressa and C.linum. The red alga G.verrucosa is found attached as epiphyte on the seagrass Halodule uninervis. The

geographical features of Tuticorin Bay creates a condition similar to that described by MacArthur (1972). The thermal outfall creates a warm water "island" (station 2) some distance to the north of warm water "continent" (station 1). Temperature increments of 7-8 ^{o}C between thermal effluent site and waste water effluent site, results in the survival of hardy local species, resistant to warm water and effective at colonising disturbed areas.

A combination of increased temperature and turbidity leads to reduced net production and chlorophyll content at station 2. The chlorophyll content is influenced by nutrients and light intensity (Behairy and El-Sayed, 1983).

The biochemical constituents of seaweeds are positively affected by the amount of nutrients present in seawater (Table 7). Solimabi et al.(1980) did not observe any relationship between nutrients and biochemical composition of seaweeds except that the high protein content is associated with high nitrogen in seawater. The waste water effluent site contain relatively higher amount of nutrients which contribute to the growth of available algae.

Protein content of Enteromorpha prolifera in a sewage outflow site was high when compared to non polluted sites (Tewari, 1972). The biochemical constituents of algae from the

waste water site in the present study was less than the control stations. This probably indicates that the positive influence of nutrients at this station is overcome by the negative influence of elevated temperature. Elevated temperatures directly influence metabolic activities of seaweeds (Vadas, 1979). Thermal plume also produce or induce indirect effects such as turbidity and sedimentation in discharge areas. When compared to other plant communities such as seagrass beds, the temperature effects on algal community is immediately apparent.

The species diversity and density of algal populations is higher in the control stations than at the thermal and waste water effluent site. According to van Tine (1981) these findings are not surprising since it is well known principle of ecology that system under stress become simpler and more homogeneous. The water depth at the hot water effluent site of TTPS is less that 2 meters. According to GESAMP (1984) the thermal plume can be deleterious to benthic communities if the receiving waters are shallow. On the other hand, if the receiving waters are sufficiently deep, the plume will spread out at some intermediate level and dilution will be enhanced due to the absence of boundary. A survey conducted by Menon et al.(1993) at Tuticorin Coast revealed that for the past 7-8 years there were rapid changes in algal population associated with major alterations of the environment. Another significant observation made by them is

that seagrasses have superseded seaweeds. Sedimentation caused by excessive deposition of flyash prevented the seaweeds to anchor themselves on the muddy bottom.

The results of the study on the productivity, chlorophyll content and biochemical constituents of seaweeds indicate that the effluents of TTPS has an adverse impact on the algal populations of Tuticorin Bay. Elevated temperatures of the thermal plume prevents the survival of algae in the near areas of the discharge site. The waste water effluents in combination with the increased temperature negatively affects the physiology and biochemistry of the few species of algae that survive in the area. The overflow of flyash from the flyash pond into the intertidal area has created an artificial, non productive, shallow and deleterious environment devoid of bottom vegetation.

Chapter 3

Heavy Metals in Seawater, Sediments and Seaweeds

INTRODUCTION

Pollution by metal arises from various land based operations such as mining, milling and smelting activities. Some of the metals may enter the sea through the aquatic route while a certain proportion reaches the oceans via atmosphere and is washed out by rain. Smelter emissions and coal burning thermal plants may transmit substantial quantity of metal into atmosphere.

The products of coal combustion mainly consists of flyash, particles of unburned fuel, nitrogen oxides and unburned hydrocarbon. Estimated production of flyash in India is about 40 million tons per annum. It is calculated that for generation of 1 MW of power, 10 metric tons of coal is required. This generates 4 metric tons of ash. The flyash generated from the Tuticorin Thermal Power Station (TTPS) is collected by electrostatic precipitators (ESP) and mixed with seawater to form a slurry which is pumped to the flyash pond. The flyash pond of TTPS was constructed by enclosing a water area of Tuticorin Bay with a dyke of 2 km. in length. The dyke has a foundation of large loose rock boulders through which seawater freely enters the pond during high tide and when tide recedes the flyash leaches out to the Tuticorin Bay. Flyash is a complex mixture of various solids, semisolids and gaseous phases consisting of numerous inorganic

and organic compounds. The major heavy metals present in flyash are Copper, Lead, Nickel, Zinc, Iron, Aluminium, Chromium, Magnesium and Mercury etc. Here in this study Copper, Lead, Nickel, Zinc and Iron were analysed in Seawater, Sediments and Seaweeds.

Another source of pollution from TTPS is the discharge of waste water. The amount of waste water discharged is approximately 54 tons/day. This consists mainly of acidic and alkaline chemical solutions used in cleaning power plant equipments, acid water drainage from coal storage and waste water contaminated with petroleum products such as oil and grease. In addition to pollution by flyash and waster water effluents, the discharge of hot water also plays and important role. Water of high temperature in combination with the flyash slurry and waste water may promote the leaching of heavy metals.

The intermixing of flyash and seawater results in suspension of solids in the water column and turbidity. In course of time the flyash settles to the bottom of the intertidal area. Waste water generated from thermal power plants are harmful to the aquatic system into which they are discharged. Heavy metals are toxic because they accumulate in the organs of marine organisms such as seaweed, fishes and shrimps.

This chapter, therefore deals with the heavy metal concentration of :

i) seawater and sediments of polluted and control areas of Tuticorin Bay and

ii) the heavy metal content of seaweeds resulting from bioaccumulation.

A review of literature pertaining to heavy metals in thermally polluted marine water areas revealed that there is no detailed work carried out in this field. There are, however, numerous studies on heavy metals of natural marine waters and other polluted systems.

The heavy metal concentrations of seawater, sediments, fishes and seaweeds have been reported from different parts of the world (Constantani et al., 1991; Schintu et al., 1991; Ashraf et al., 1992; Dunn et al., 1992; Herut et al., 1993; Tariq et al., 1993; Sfriso et al., 1995). These studies are either baseline observation or deals with domestic and industrial pollution.

In India, heavy metals in seawater and sediments of both the west coast and east coast is available in the literature (Murthy et al., 1978; Sen Gupta et al., 1978; Matkar et al., 1981; Zingde and Desai 1981; Patel et al., 1985; Rao and Indusekhar, 1986; Kumar and Pillai, 1990; Kannan et al., 1992).

Ganesan and Kannan (1995) studied iron and manganese concentrations in seawater and marine algae of Tuticorin Coast. They found that the iron and manganese were appreciably higher than the other parts of the Indian Coast. Decomposition of organic particulates and dead phytoplankton cells contributed to the high heavy metal values along Saurashtra Coast (Rao and Indusekhar, 1986).

UNEP (1985) presents data on the concentrations of heavy metals of Indian Ocean region. Ganesan and Kannan (1995) found high content of iron and manganese in the sediment of Tuticorin Coast during monsoon and postmonsoon seasons due to increased inputs from land runoff. Fine grained sediment hold relatively high concentration of metals (Murthy et al., 1978). The above studies indicate that the trace metal content of seawater and sediment is many fold higher than that of unpolluted systems. The studies also underline the need for close monitoring of heavy metals in areas susceptible to pollution.

Many species of macroalgae accumulate pollutants in their tissues. This capacity to absorb pollutants has long been recognized as a valuable tool for monitoring environmental pollution. Since the first study on metal level in macroalgae (Black and Mitchell, 1952) different species have been used as

indicators of heavy metal pollution (Patel et al., 1980; Cullinane et al., 1987; Ramirez et al., 1990; Rajendran et al., 1993; Rao et al., 1995; Jayasekera and Rossback, 1996; Vasquez and Guerra, 1996).

Environmental parameters such as temperature and salinity can affect metal uptake in algae by directly affecting growth (Burdon-Jones et al., 1982). Seasonal variation in uptake of heavy metals by algae has also been reported (Haug et al., 1974; Phillips, 1977; Rao and Indusekhar, 1989; Munda and Hudnik, 1991; Sfriso et al., 1995; Haritonidis and Malea, 1995; Riget et al., 1995). Ganesan and Kannan (1995) found significant correlation between high levels of metals in algae with high concentrations in seawater. However, Malea et al.(1995) correlated seasonal variation in heavy metals of algae with their concentrations in sediments and was not significantly related with their dissolved level is seawater.

The concentration of heavy metals in seaweeds in the west coast of India is well documented (Zingde et al., 1976; Agadi et al., 1978; Patel et al., 1980; Rao and Indusekhar, 1986, 1987, 1989; Fernandez et al., 1995). Kumar et al.(1990) found that the concentration of heavy metal in Sargassum tenerimum in the vicinity of the discharge of a caustic soda plant is comparatively higher than the control station. The importance of

monitoring the temporal variation and flux rates of various heavy and trace metals in the species linking the aquatic food chain and leading to critical levels is mentioned by Sobha et al.(1992).

Along the east coast of India, heavy metal concentration in seaweeds is reported (Rajendran et al., 1993; Ganesan and Kannan, 1995; Rao et al., 1995). Copper and zinc concentration of seaweeds analysed by Ganesan et al.(1991) was higher than the maximum permissible limits prescribed for seafoods. Kannan et al.(1992) observed greater concentration factor for copper and iron than those of other metals in seagrasses.

The review of literature reveals that heavy metal concentration of seawater and sediments in natural and polluted conditions are well studied. The importance of seaweeds as indicator of pollution are also well understood. Heavy metals from domestic, industrial and sewage pollution and their effect on algae has also received some attention. However, studies on heavy metals of algae from thermal effluent areas are lacking. Therefore, the present study is aimed as a preliminary documentation of heavy metal in algae from an area of thermal pollution.

MATERIALS AND METHODS

Seawater and sediment samples were collected from stations 1 to 5 every month from October 1987 to September 1989. The stations were fixed as described in chapter 1. Surface water samples were collected in triplicate in acid washed plastic bottles. Top layer sediments were collected in plastic bags. Seaweeds were collected from stations 2 to 5.

Heavy metals such as copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn) and Iron (Fe) in seawater, sediments and seaweeds were analysed using standard methods. Polarized Zeeman Atomic Absorption Spectrophotometer (AAS) incorporated with automatic curve correction microprocessor was utilized for metal analysis. The light source was intersitron Hollow Cathode Lamp (HCL). Air-acetylene was the oxidant-fuel combination with a compatible 10 cm burner head.

Metals in seawater: Heavy metals in seawater was determined following the Ammonium Pyrollidine Dithiocarbamate (APDC) and Methyl Isobutyl Ketone (MIBK) extraction method (Brooks et al., 1967).

Water samples were filtered through 0.45 micron millipore filter paper and pH was adjusted between 4 and 5 using hydrochloric acid (6N). To 750 ml seawater sample taken in 1 litre polypropylene flask, 35 ml of MIBK and 7 ml of 1% APDC solution was added. The samples were then equilibrated for 30 minutes on a mechanical shaker. The phases were separated by means of separatory funnel and the organic phases were stored for analysis. In order to prepare a working curve, another 20 ml of MIBK was added to the sample of extracted seawater and phases were again separated after a further 5 minutes equilibration. The purpose was to ensure that the seawater used for calibration was as free as possible from the trace elements. Extracted water samples were aspirated into atomic absorption spectrophotometer within 3 hours of extraction. Results are expressed in µg/L.

Metals in sediments: Heavy metals in sediments were extracted and analysed according to the method of Sinex et al.(1980).

Sediment samples were oven dried at 80 ^{o}C and sieved to eliminate shell fragments, visible organisms and roots. To 5 gm of sample in 500 ml boiling flask, 90 ml concentrated nitric acid and 10 ml concentrated hydrochloric acid were added. The contents were refluxed on a hot plate for 4 hours with vigorous boiling. The acid extracts are centrifuged, filtered and brought to a fixed volume and analysed by atomic absorption spectrophotometer within 3 hour of extraction. Results are expressed in µg/gm.

Metals in seaweeds: Heavy metals from seaweeds were extracted and analysed according to the method of Say et al.(1986).

Dried material was ground to a fine powder and then redried for 3 hours. Duplicate sub samples of each seaweed weighing 1 gm were digested with 10 ml of 2M nitric acid and heated to near dryness. The residue was then resuspended in 10 ml of 2M nitric acid, filtered and made upto 25 ml with metal free double distilled water and stored in pre (acid) cleaned polyethylene containers. Reagent blanks were also prepared. The concentration of heavy metals was determined by aspirating the samples into a atomic absorption spectrophotometer and results expressed as ug/gm dry wt.

RESULTS

Table 1 gives seasonal averages of heavy metal values of seawater and sediments. The heavy metals, in general, show a decreasing trend from station 1 to 5 for both seawater and sediments. Lead, nickel and zinc in seawater were high at station 2 than that of station 1, while in sediment all the heavy metal studied were comparatively higher in station 2. Seasonal averages of heavy metal concentrations of different species of seaweeds are presented in Table 2. Except iron all other metals in G.verrucosa were high during the monsoon months. In the case of

E.compressa, copper and iron were high during postmonsoon and monsoon while the other metals were high during monsoon. Zinc and iron were high during postmonsoon months in C.linum while the copper, lead and nickel values predominated during monsoon.

The results of two-way ANOVA between stations and seasons for heavy metals in seawater and sediments are presented in Table 3. The variation in iron between season is not significant ($P<0.05$). In sediments the concentration of lead was insignificant between stations while zinc and iron concentrations did not vary significantly between seasons. The accumulation of copper in G.verrucosa and C.linum was not different between stations (Table 4). In addition to copper the variations in nickel of C.linum was also insignificant between stations ($P>0.05$).

Correlation matrices of environmental parameters with seawater at stations 1,2 and 5 are given in Table 5. Water temperature and nitrate influenced the variations of zinc, iron and copper at station 1. At station 2, copper, lead and zinc were negatively related with phosphate while iron was positively related. Turbidity have a positive influence on variations in most of the metal studied. Table 6 presents the correlation matrices of environmental parameters, metals in seawater and sediments with nickel and zinc in seaweeds. All parameters except phosphate showed significant positive relation with nickel and

zinc values of G.verrucosa and E.compressa at station 2. At station 5 the nickel and zinc of algae were positively related with the respective metals in seawater. Linear regression of heavy metals in seawater and seaweeds at station 2 and 5 are presented in Table 7.

The bimonthly variation in heavy metal concentration at station 1, 2 and 5 in seawater and sediments are depicted in Fig. 1A to 5B. The concentration of copper in G.verrucosa (Fig. 6A), lead in E.compressa (Fig.6B) and zinc in C.linum (Fig.7A) were high at station 2 when compared to stations 3 and 5. The accumulation of nickel in G.verrucosa at station 2 closely followed the variations of nickel in seawater (Fig.7B). A similar trend is noticed in the case of zinc in E.compressa (Fig.8A) and iron in C.linum (Fig.8B).

Table 1 : Seasonal averages of heavy metal values in seawater and sediments.

Parameter	Season	Station				
		1	2	3	4	5
Seawater (µg/L)						
Copper	Premonsoon	41.40	38.25	22.93	13.52	6.93
	Monsoon	57.21	41.30	31.52	16.72	9.35
	Postmonsoon	46.53	37.51	29.21	14.45	8.42
Lead	Premonsoon	14.85	15.65	11.56	12.25	7.45
	Monsoon	31.85	31.53	20.95	17.03	8.81
	Postmonsoon	18.82	19.21	11.64	13.35	8.95
Nickel	Premonsoon	26.45	28.55	18.70	24.94	9.21
	Monsoon	50.65	55.25	27.55	27.91	12.54
	Postmonsoon	32.96	35.85	19.45	24.92	7.23
Zinc	Premonsoon	19.43	31.10	16.93	14.11	11.68
	Monsoon	26.02	50.12	26.31	24.10	15.33
	Postmonsoon	26.44	40.73	22.00	23.76	13.11
Iron	Premonsoon	192.25	188.89	132.78	37.68	43.93
	Monsoon	302.96	291.41	173.52	49.61	48.87
	Postmonsoon	292.91	211.63	164.11	45.27	51.52
Sediment (µg/gm)						
Copper	Premonsoon	35.25	35.41	25.68	14.80	16.13
	Monsoon	63.66	64.96	35.81	19.27	17.90
	Postmonsoon	37.90	48.26	28.84	14.82	16.51
Lead	Premonsoon	20.21	17.96	13.44	15.99	9.71
	Monsoon	22.50	27.50	17.44	20.17	20.31
	Postmonsoon	19.97	25.70	24.77	20.44	12.81
Nickel	Premonsoon	50.83	46.65	33.75	21.47	13.05
	Monsoon	60.80	64.29	40.16	24.38	14.29
	Postmonsoon	52.61	59.73	47.65	28.73	21.04
Zinc	Premonsoon	26.43	30.29	32.93	27.83	15.49
	Monsoon	49.09	47.03	39.11	21.70	21.37
	Postmonsoon	32.95	47.98	29.96	26.49	17.07
Iron	Premonsoon	26184	26113	15692	6888	4404
	Monsoon	30252	32770	7763	5532	4499
	Postmonsoon	31430	32471	9105	4447	4363

Table 2 : Seasonal averages of heavy metal values (µg/gm) of different species of seaweeds.

Parameter	Season	Stations			
		2	3	4	5
G. verrucosa					
Copper	Premonsoon	4.44	4.25	3.92	4.41
	Monsoon	10.33	6.73	4.62	4.32
	Postmonsoon	6.67	5.10	4.72	4.48
Lead	Premonsoon	2.00	1.50	1.11	1.06
	Monsoon	4.20	2.75	1.32	1.39
	Postmonsoon	3.75	2.05	1.32	1.00
Nickel	Premonsoon	21.42	12.54	6.24	6.08
	Monsoon	35.77	16.38	9.24	9.36
	Postmonsoon	21.21	13.09	6.79	6.47
Zinc	Premonsoon	45.31	32.28	9.17	8.01
	Monsoon	68.08	48.15	21.74	21.68
	Postmonsoon	50.42	38.70	17.22	17.80
Iron	Premonsoon	2464	2387	1031	1218
	Monsoon	3097	2235	1843	1210
	Postmonsoon	3297	2415	1190	1210
E. compressa					
Copper	Premonsoon	16.07	11.82	7.27	5.36
	Monsoon	14.07	14.27	9.19	5.99
	Postmonsoon	17.56	11.57	9.82	6.07
Lead	Premonsoon	6.31	2.91	6.49	2.43
	Monsoon	9.59	4.39	3.59	3.36
	Postmonsoon	7.97	4.03	2.96	3.12
Nickel	Premonsoon	17.73	9.72	10.51	9.96
	Monsoon	23.44	19.25	13.74	13.47
	Postmonsoon	20.69	14.13	14.97	12.49
Zinc	Premonsoon	63.91	45.64	24.27	18.25
	Monsoon	90.92	64.64	31.30	25.82
	Postmonsoon	76.62	57.87	32.36	29.42
Iron	Premonsoon	3572	3192	1061	975
	Monsoon	4169	3102	1336	1049
	Postmonsoon	4637	3574	1210	935
C. linum					
Copper	Premonsoon	7.88	8.85	6.69	4.50
	Monsoon	15.77	11.39	5.41	5.39
	Postmonsoon	9.91	10.72	7.58	6.97
Lead	Premonsoon	3.67	5.04	1.93	1.67
	Monsoon	8.81	5.60	2.21	1.77
	Postmonsoon	5.03	5.30	2.07	1.79
Nickel	Premonsoon	10.03	7.88	8.01	9.87
	Monsoon	20.53	20.64	10.48	13.16
	Postmonsoon	15.93	16.28	9.81	13.41
Zinc	Premonsoon	51.02	24.10	18.07	21.12
	Monsoon	60.74	29.70	20.97	23.60
	Postmonsoon	62.35	31.77	22.31	24.00
Iron	Premonsoon	4923	3065	901	1001
	Monsoon	4865	4683	984	1155
	Postmonsoon	5122	4907	1055	1288

Table 3 : Two-way ANOVA between stations and seasons for heavy metals in seawater and sediments.

Parameter	Source	df	SS	MSS	F	P
Seawater						
Copper	Treatment	4	3296	824	88	P<0.01
	Replicate	2	111	56	6	P<0.05
	Error	8	75	9		
Lead	Treatment	4	402	100	7	P<0.01
	Replicate	2	260	130	10	P<0.01
	Error	8	109	14		
Nickel	Treatment	4	1762	441	13	P<0.01
	Replicate	2	492	246	7	P<0.05
	Error	8	271	34		
Zinc	Treatment	4	1219	305	30	P<0.01
	Replicate	2	246	123	12	P<0.01
	Error	8	81	10		
Iron	Treatment	4	122283	30571	36	P<0.01
	Replicate	2	7464	3732	4	P>0.05
	Error	8	6788	849		
Sediment						
Copper	Treatment	4	2916	729	14	P<0.01
	Replicate	2	596	298	6	P<0.05
	Error	8	404	51		
Lead	Treatment	4	144	36	3	P>0.05
	Replicate	2	110	55	5	P<0.05
	Error	8	83	10		
Nickel	Treatment	4	3869	967	50	P<0.01
	Replicate	2	230	115	6	P<0.05
	Error	8	155	19		
Zinc	Treatment	4	1021	256	7	P<0.05
	Replicate	2	179	90	2	P>0.05
	Error	8	297	37		
Iron	Treatment	4	196×10^7	490×10^6	48	P<0.01
	Replicate	2	652×10^3	326×10^3	0	P>0.05
	Error	8	218×10^5	102×10^5		

Table 4 : Two-way ANOVA between stations and seasons of heavy metals in different species of seaweeds.

Parameter	Source	df	SS	MSS	F	P
G.verrucosa						
Copper	Treatment	3	15	5	3	P>0.05
	Replicate	2	10	5	3	P>0.05
	Error	6	11	2		
Lead	Treatment	3	9	3	12	P<0.01
	Replicate	2	2	1	4	P>0.05
	Error	6	2	0.2		
Nickel	Treatment	3	705	235	22	P<0.01
	Replicate	2	95	47	4	P>0.05
	Error	6	65	11		
Zinc	Treatment	3	3257	1086	100	P<0.01
	Replicate	2	528	264	24	P<0.01
	Error	6	66	11		
Iron	Treatment	3	$6x10^6$	$2x10^6$	23	P<0.01
	Replicate	2	$2x10^5$	$1x10^5$	1	P>0.05
	Error	6	$5x10^5$	$9x10^4$		
E.compressa						
Copper	Treatment	3	175	58	30	P<0.01
	Replicate	2	3	1	1	P>0.05
	Error	6	12	2		
Lead	Treatment	3	44	15	7	P<0.05
	Replicate	2	1	1	0.3	P>0.05
	Error	6	13	2		
Nickel	Treatment	3	135	45	16	P<0.01
	Replicate	2	62	31	11	P<0.01
	Error	6	17	3		
Zinc	Treatment	3	5430	1810	67	P<0.01
	Replicate	2	491	246	9	P<0.05
	Error	6	163	27		
Iron	Treatment	3	$2x10^7$	$7x10^6$	99	P<0.01
	Replicate	2	$3x10^5$	$1x10^5$	2	P>0.05
	Error	6	$4x10^5$	$7x10^4$		
C.linum						
Copper	Treatment	3	68	23	5	P>0.05
	Replicate	2	13	7	1	P>0.05
	Error	6	29	5		
Lead	Treatment	3	41	14	9	P<0.05
	Replicate	2	9	2	2	P>0.05
	Error	6	10	2		
Nickel	Treatment	3	57	19	3	P>0.05
	Replicate	2	62	31	5	P>0.05
	Error	6	41	7		
Zinc	Treatment	3	2716	905	210	P<0.01
	Replicate	2	95	48	11	P<0.01
	Error	6	26	4		
Iron	Treatment	3	$3x10^7$	$1x10^7$	59	P<0.01
	Replicate	2	$8x10^5$	$4x10^5$	2	P>0.05
	Error	6	$1x10^6$	$2x10^5$		

Table 5 : Correlation matrices of environmental parameters with seawater at stations 1,2 and 5.

Parameters	WT	Pho	Nit	Tub	Cu	Pb	Ni	Zn
Station 1								
Water temp.	1.00							
Phosphate	-0.01	1.00						
Nitrate	0.23	0.37	1.00					
Turbidity	0.20	0.01	-0.10	1.00				
Copper	0.27	-0.26	-0.46*	0.29	1.00			
Lead	0.17	0.38	-0.18	0.40	0.47*	1.00		
Nickel	0.05	-0.20	-0.36	-0.09	0.53*	0.12	1.00	
Zinc	0.45*	0.06	-0.18	0.34	0.84*	0.60*	0.28	1.00
Iron	0.46*	0.19	-0.05	0.38	0.71*	0.61*	0.17	0.97*
Station 2								
Water temp.	1.00							
Phosphate	-0.29	1.00						
Nitrate	-0.02	0.18	1.00					
Turbidity	0.04	-0.62*	0.17	1.00				
Copper	0.31	-0.50*	-0.34	0.64*	1.00			
Lead	0.35	-0.71*	-0.21	0.62*	0.73*	1.00		
Nickel	0.09	0.03	-0.44*	0.03	0.44*	0.15	1.00	
Zinc	0.43*	-0.65*	-0.09	0.77*	0.80*	0.72*	0.19	1.00
Iron	0.29	0.51*	-0.42*	0.60*	0.92*	0.67*	0.57*	0.78*
Station 5								
Water temp.	1.00							
Phosphate	-0.40	1.00						
Nitrate	0.16	-0.18	1.00					
Turbidity	-0.33	-0.10	-0.15	1.00				
Copper	0.07	0.15	-0.21	0.17	1.00			
Lead	-0.30	-0.13	0.29	0.28	0.32	1.00		
Nickel	0.06	0.07	0.04	0.01	0.34	0.61*	1.00	
Zinc	0.30	-0.14	-0.18	0.15	0.67*	0.50*	0.66*	1.00
Iron	0.29	-0.02	-0.16	-0.10	0.38	-0.18	0.27	0.37

* indicates significant correlation

Table 6 : Correlation matrices of environmental parameters, metals in seawater and sediment with metals in seaweeds.

Parameter	G. verrucosa		E. compressa	
	Ni	Zn	Ni	Zn
Station 2				
Water temperature	0.24	0.30	0.48*	0.33
Phosphate	-0.44*	-0.48*	-0.47*	-0.67*
Turbidity	0.59*	0.61*	0.58*	0.72*
Nickel in seawater	0.85*	0.88*	0.77*	0.83*
Zinc in seawater	0.72*	0.77*	0.88*	0.88*
Nickel in sediment	0.48*	0.66*	0.58*	0.62*
Zinc in sediment	0.38*	0.53*	0.64*	0.63*
Station 5				
Water temperature	-0.07	0.13	0.13	0.13
Phosphate	-0.06	-0.35	-0.28	-0.26
Turbidity	0.30	0.19	0.17	-0.01
Nickel in seawater	0.14	0.55*	0.42*	0.55*
Zinc in seawater	0.48*	0.84*	0.82*	0.71*
Nickel in sediment	-0.06	0.15	0.29	0.32
Zinc in sediment	0.40	0.34	0.27	0.19

* indicates significant correlation

Table 7 : Linear regression of heavy metals in seawater and seaweeds at stations 2 and 5. (n = 24)

Heavy metal	Station 2		Station 5	
	Equation	r	Equation	r
G.verrucosa				
Copper	3.66-0.23 Cu in s.w	0.91	6.95+1.00 Cu in s.w	-0.80
Lead	2.11+0.40 Pb in s.w	0.51	0.83+2.08 Pb in s.w	0.70
Nickel	22.92-2.00 Ni in s.w	0.86	6.14+0.46 Ni in s.w	0.21
Zinc	4.69+1.32 Zn in s.w	0.68	11.51-8.85 Zn in s.w	0.86
Iron	2052+3.90 Fe in s.w	0.45	1361+4.02 Fe in s.w	-0.25
E.compressa				
Copper	21.43-0.12 Cu in s.w	-0.53	4.39+0.58 Cu in s.w	0.25
Lead	1.63-2.66 Pb in s.w	0.91	1.93+5.12 Pb in s.w	0.61
Nickel	6.10+0.61 Ni in s.w	0.82	9.73+0.90 Ni in s.w	0.37
Zinc	2.85+2.18 Zn in s.w	0.89	5.89+6.02 Zn in s.w	0.70
Iron	2.57-35.6 Fe in s.w	0.23	1175+3.94 Fe in s.w	-0.32
C.linum				
Copper	2.70+0.29 Cu in s.w	0.84	4.21+0.58 Cu in s.w	0.22
Lead	0.75+2.10 Pb in s.w	0.76	1.41+1.09 Pb in s.w	0.51
Nickel	1.65-0.69 Ni in s.w	0.62	12.20+0.02 Ni in s.w	0.56
Zinc	25.04+0.90 Zn in s.w	0.81	17.20+1.81 Zn in s.w	0.41
Iron	2184+9.50 Fe in s.w	0.53	529+12.9 Fe in s.w	0.49

s.w indicates seawater

Fig 1A : Fluctuations of copper values in seawater at stations 1, 2 and 5

Copper in seawater

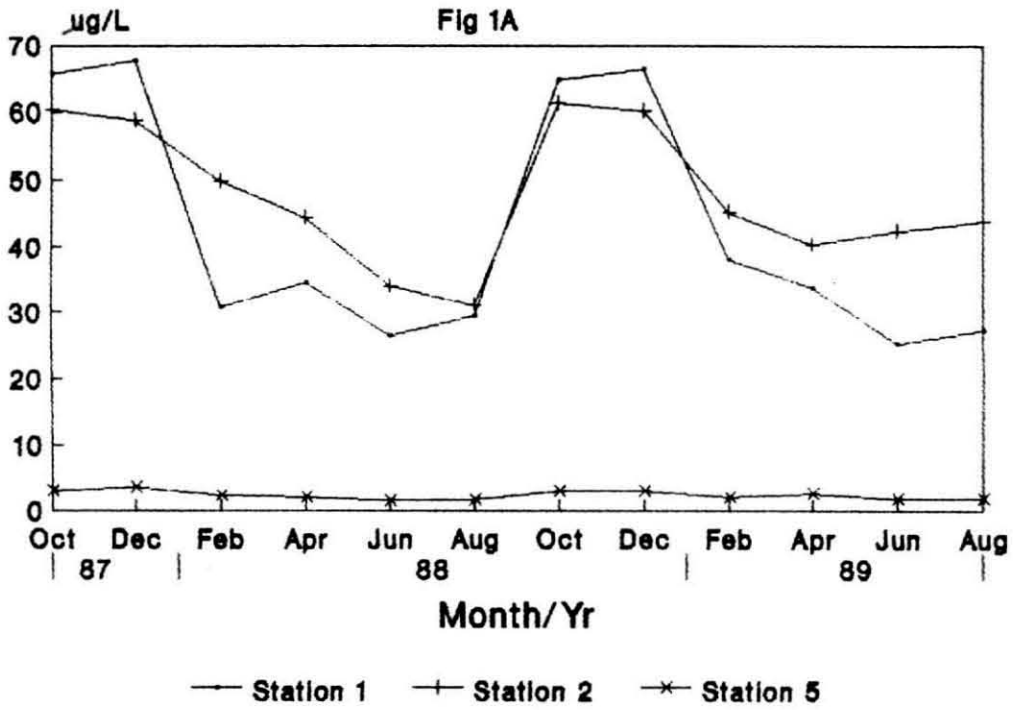


Fig 1B : Fluctuations of lead in seawater at stations 1, 2 and 5

Lead in seawater

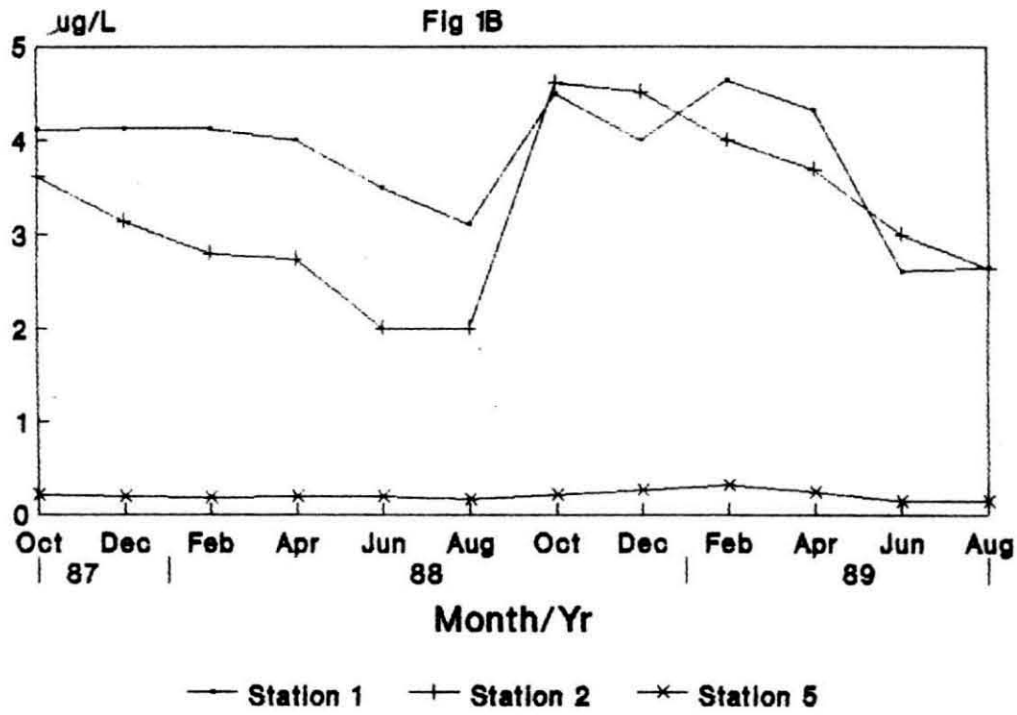


Fig 2A : Fluctuations of nickel in seawater at stations 1, 2 and 5

Nickel in seawater

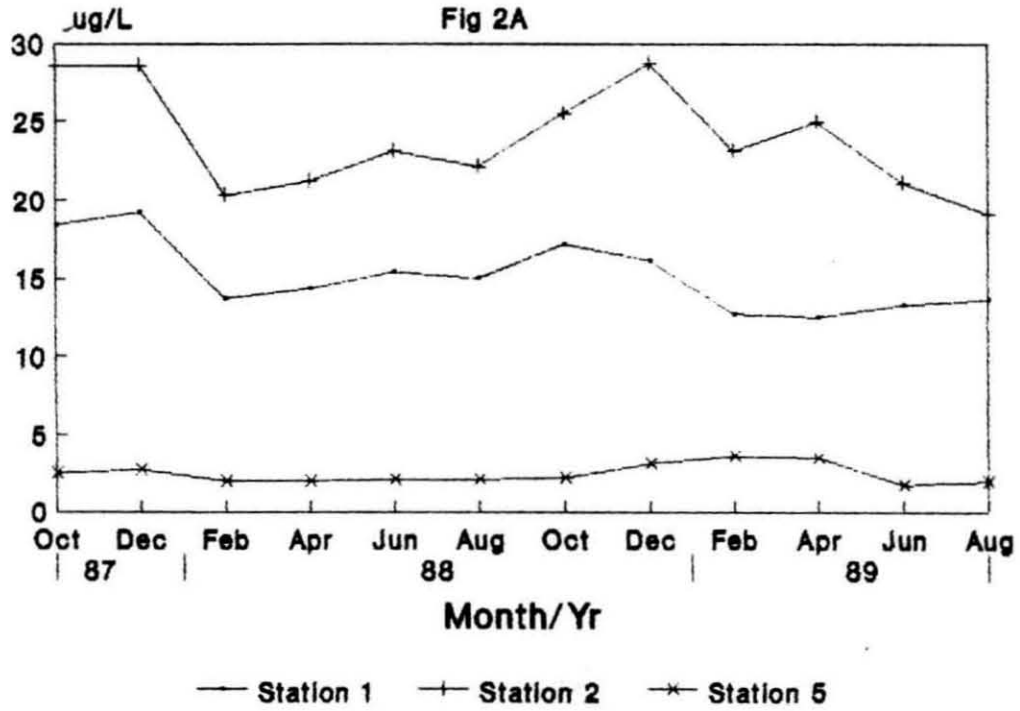


Fig 2B : Fluctuations of zinc in seawater at stations 1, 2 and 5

Zinc in seawater

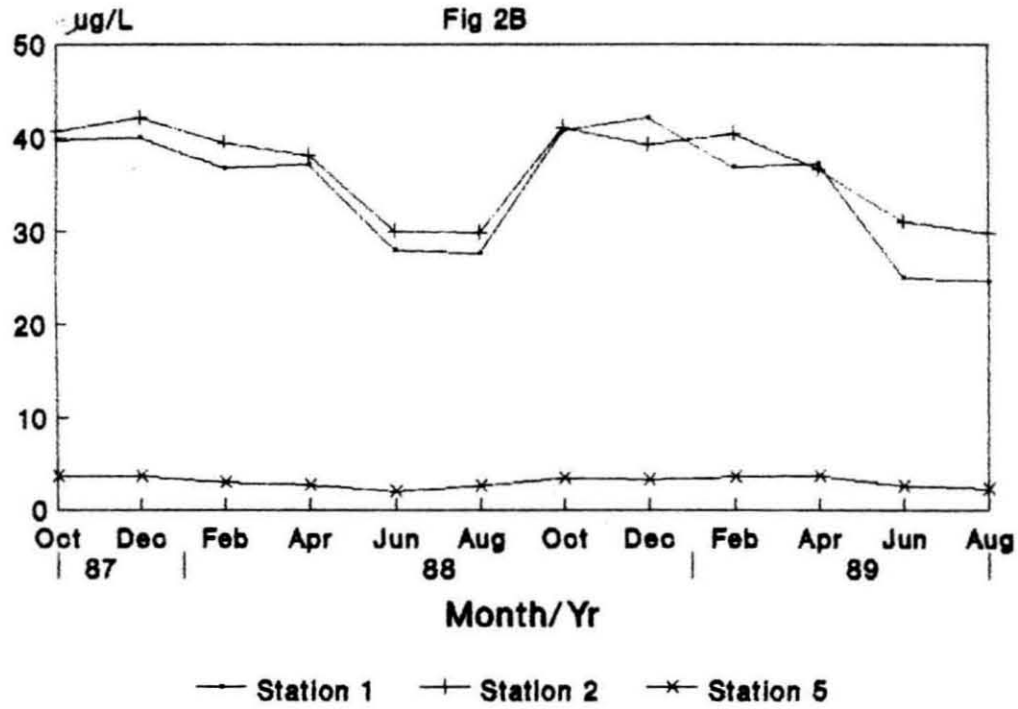


Fig 3A : Fluctuations of iron in seawater at stations 1, 2 and 5

Iron in seawater

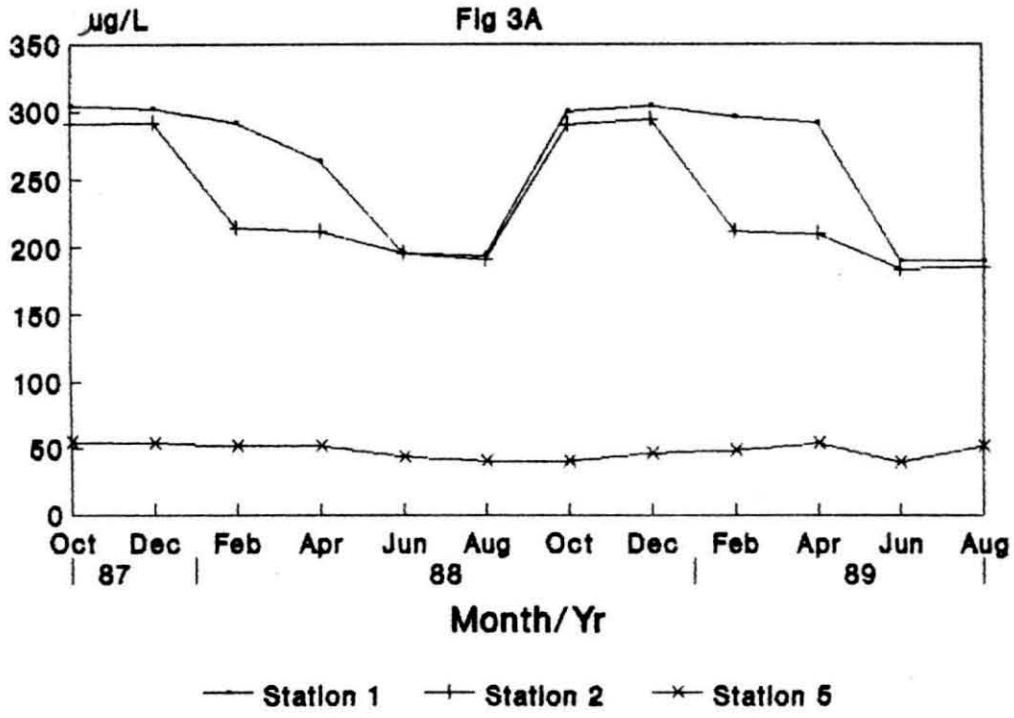


Fig 3B : Bimonthly values of copper in sediment at stations 1, 2 and 5

Copper in sediment

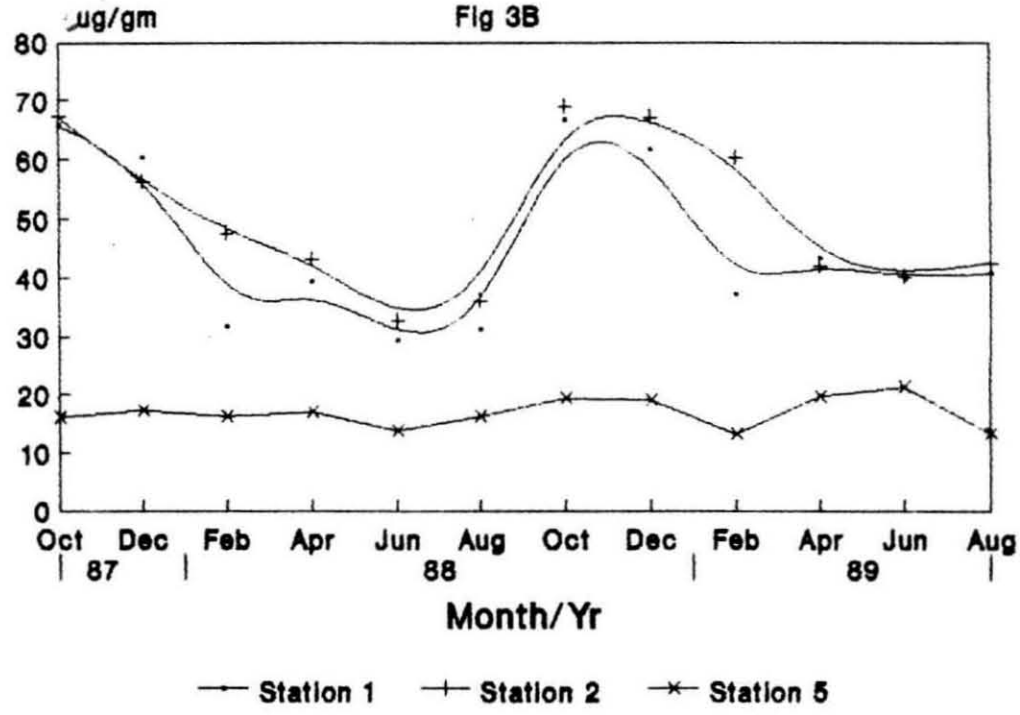


Fig 4A : Bimonthly values of lead in sediment at stations 1, 2 and 5

Lead in sediment

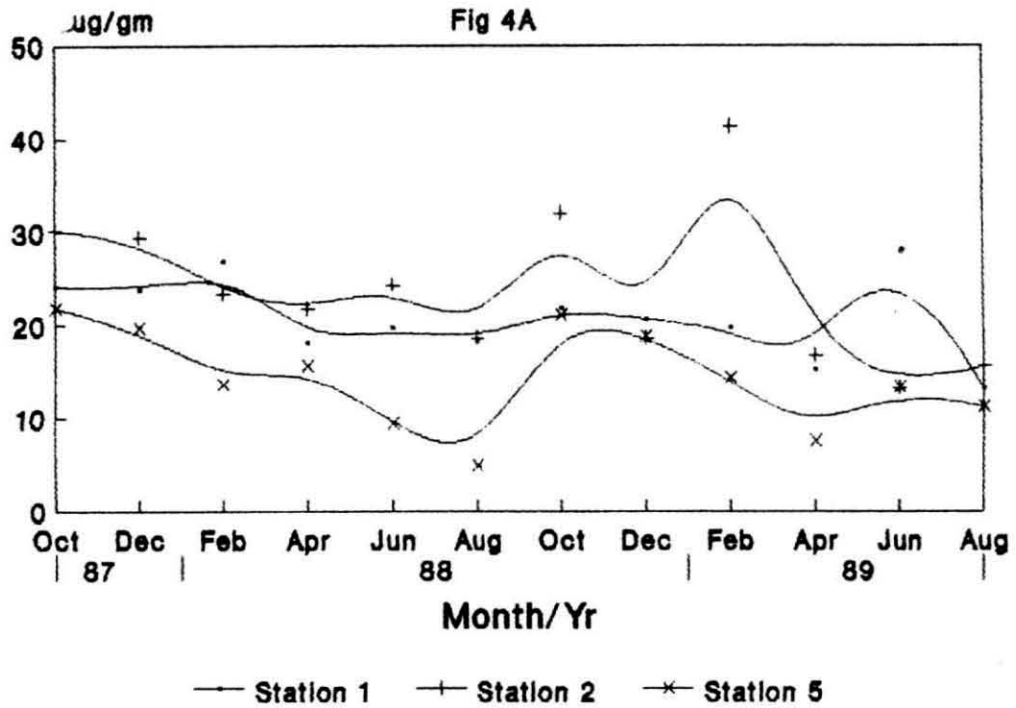


Fig 4B : Bimonthly values of nickel in sediment at stations 1, 2 and 5

Nickel in sediment

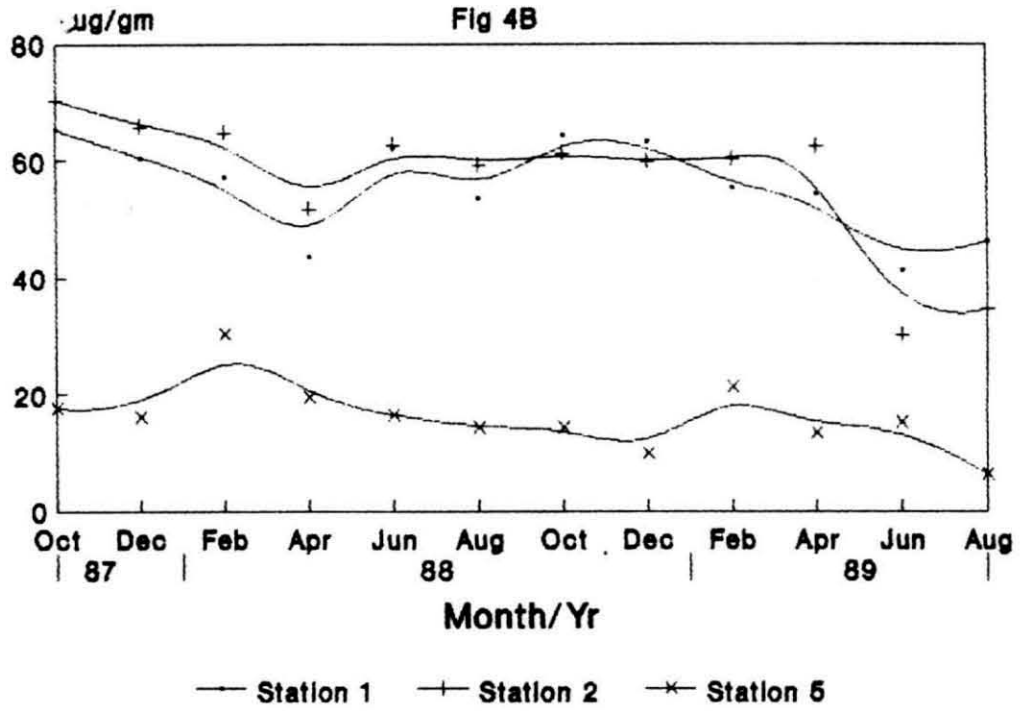


Fig 5A : Bimonthly values of zinc in sediment at stations 1, 2 and 5

Zinc in sediment

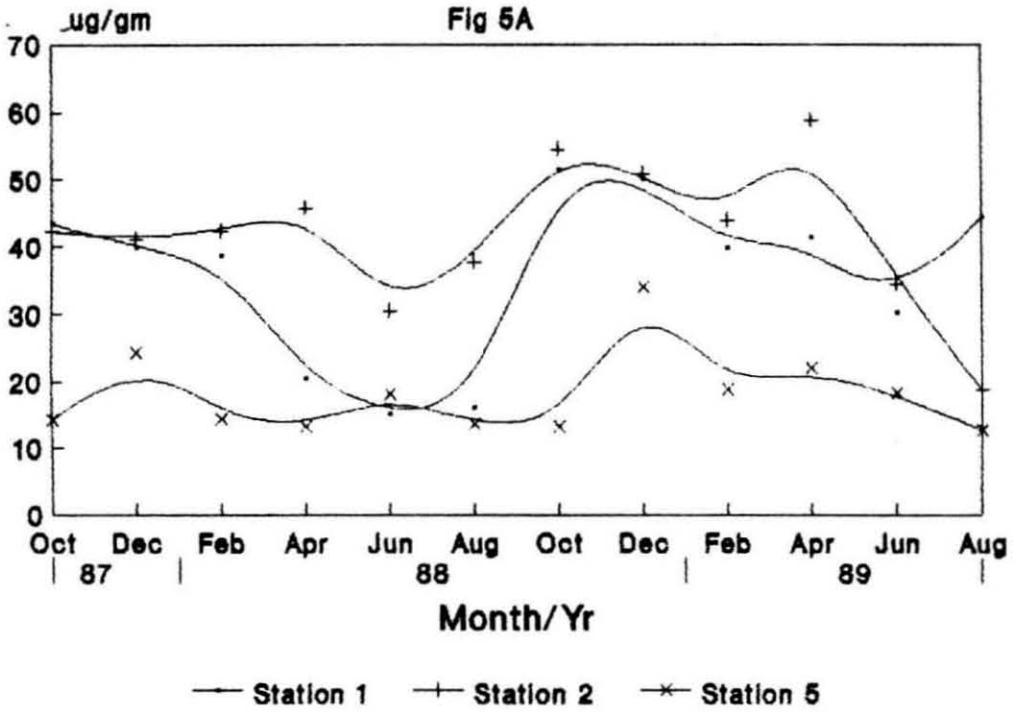


Fig 5B : Bimonthly values of iron in sediment at stations 1, 2 and5

Iron in sediment

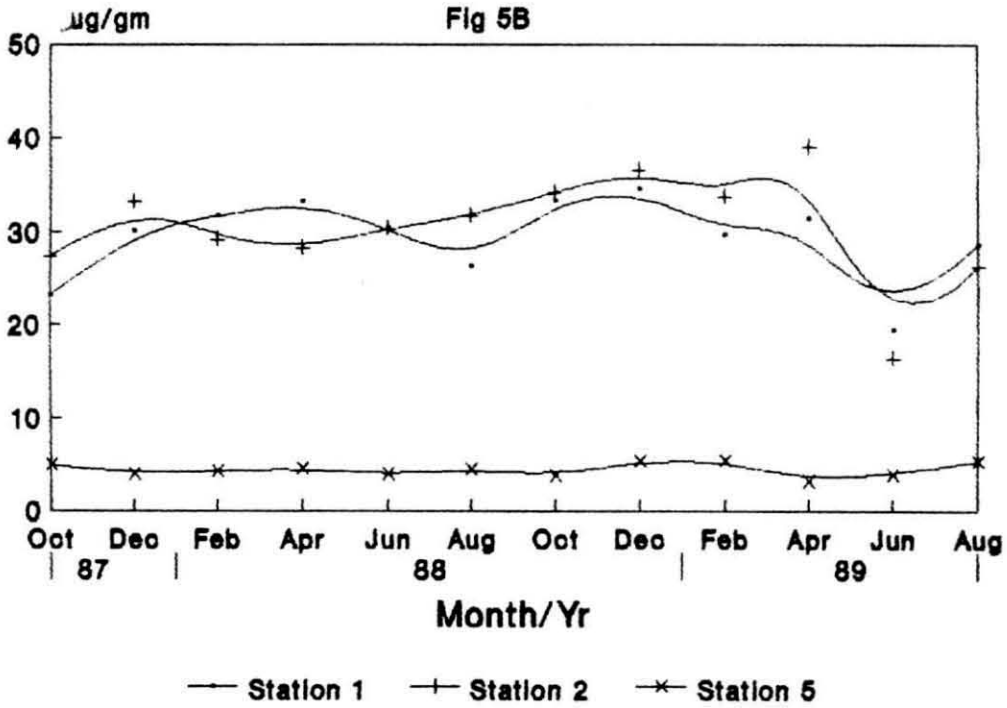


Fig 6A : Copper in Gracilaria verrucosa at stations 1, 2 and 5

Copper - Gracilaria verrucosa

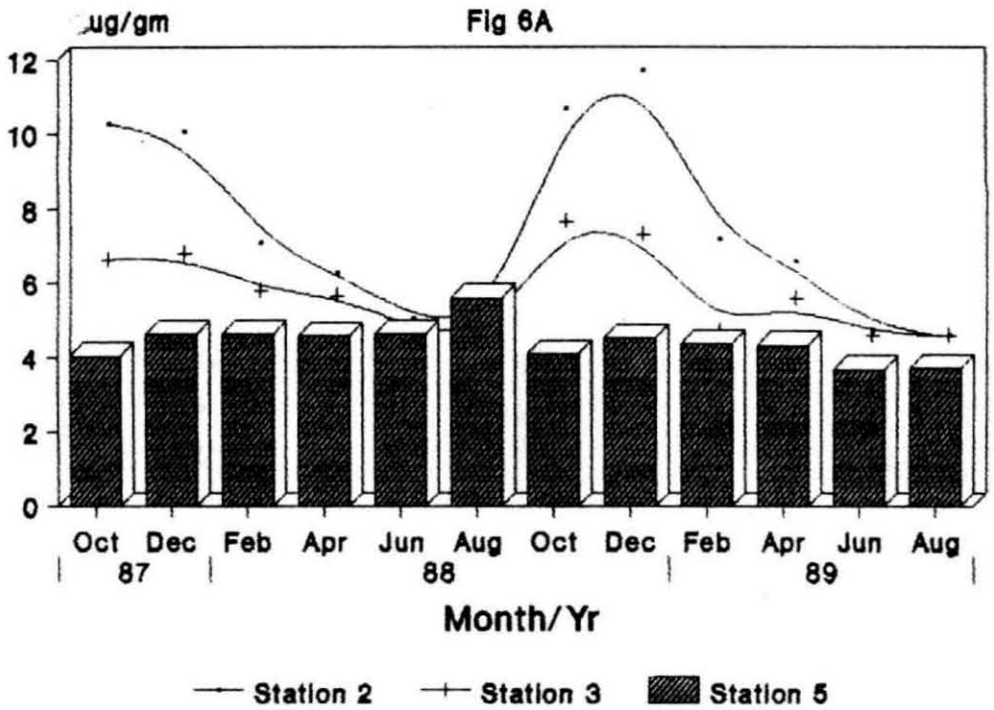
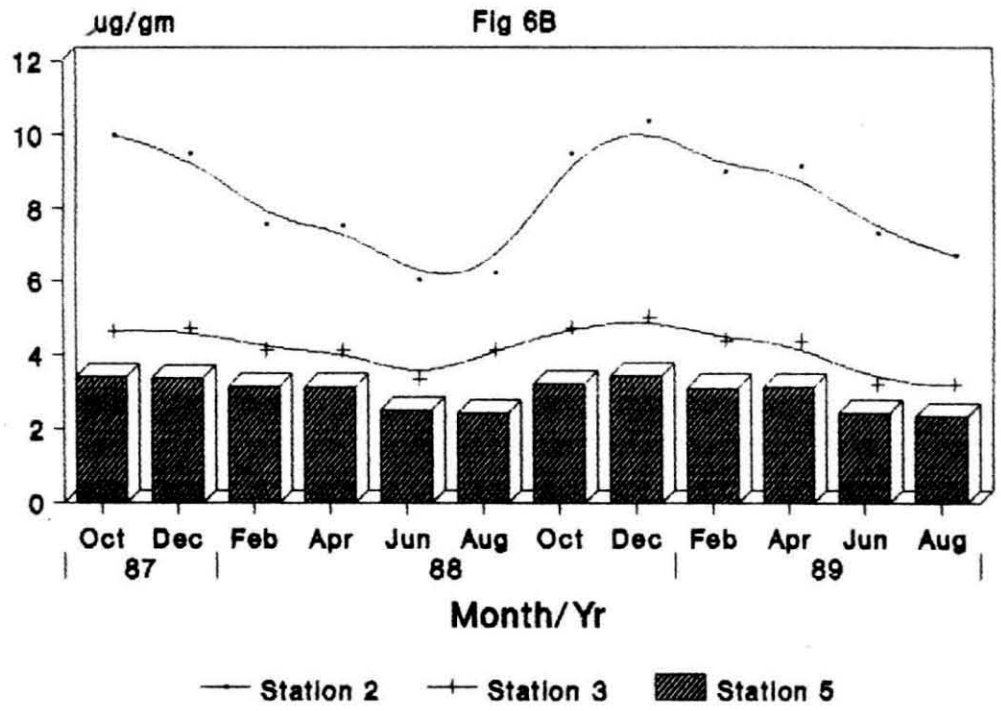


Fig 6B : Lead in Enteromorpha compressa at stations 2, 3 and 5

Lead - Enteromorpha compressa



Zinc - Chaetomorpha linum

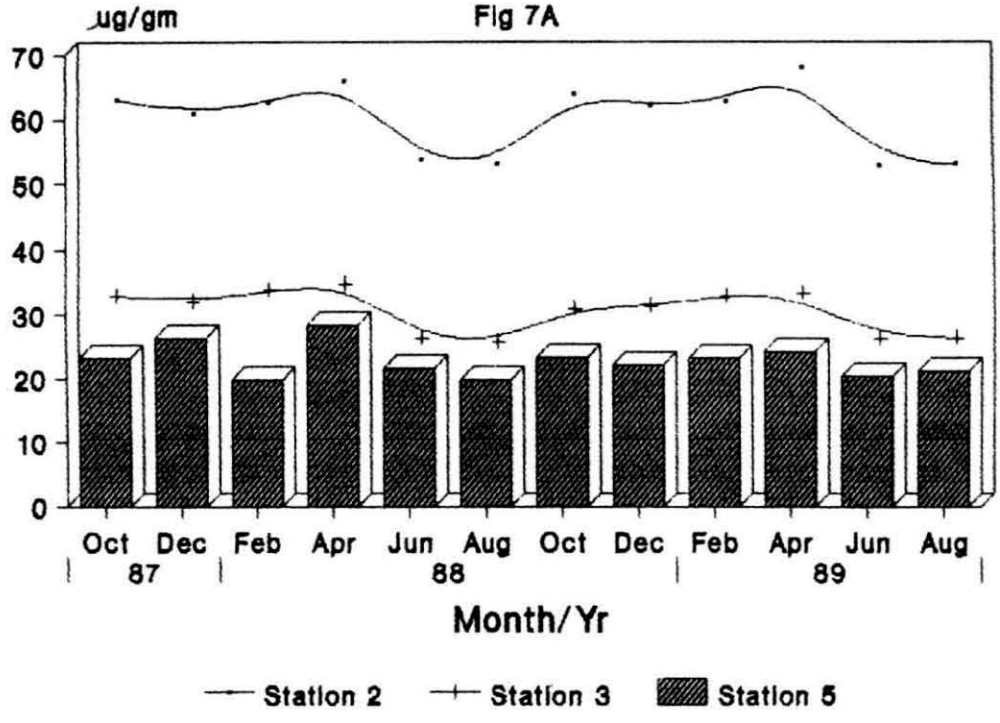


Fig 7B : Nickel in seawater and Gracilaria verrucosa at stations 2 and 5

Nickel in Seawater and G.verrucosa

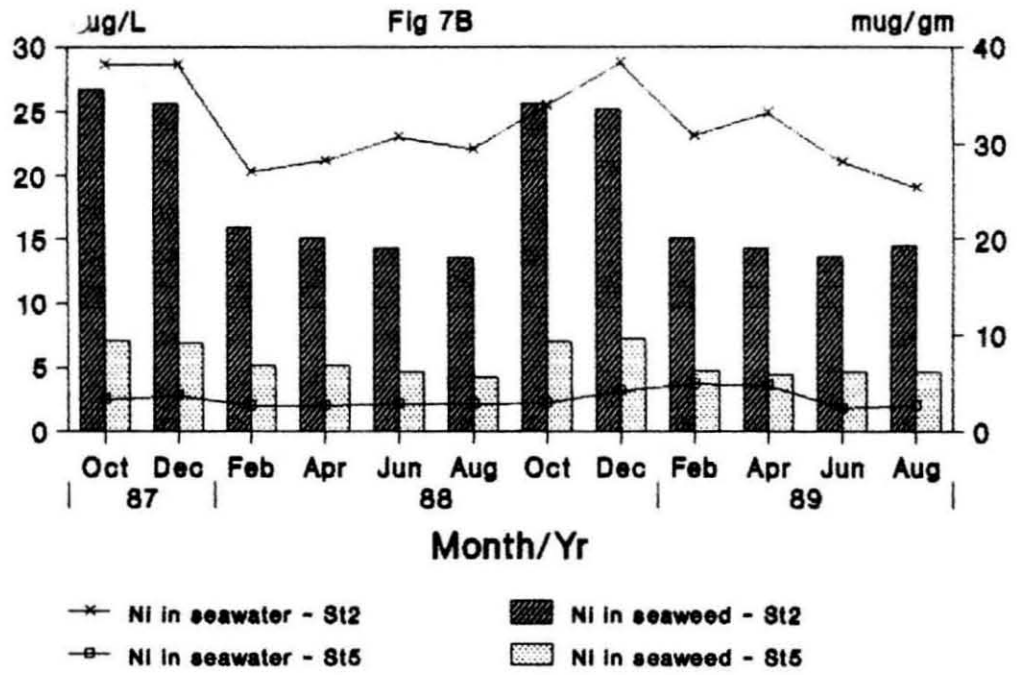


Fig 8A : Zinc in seawater and Enteromorpha compressa at stations 2 and 5

Zinc in Seawater and E.compressa

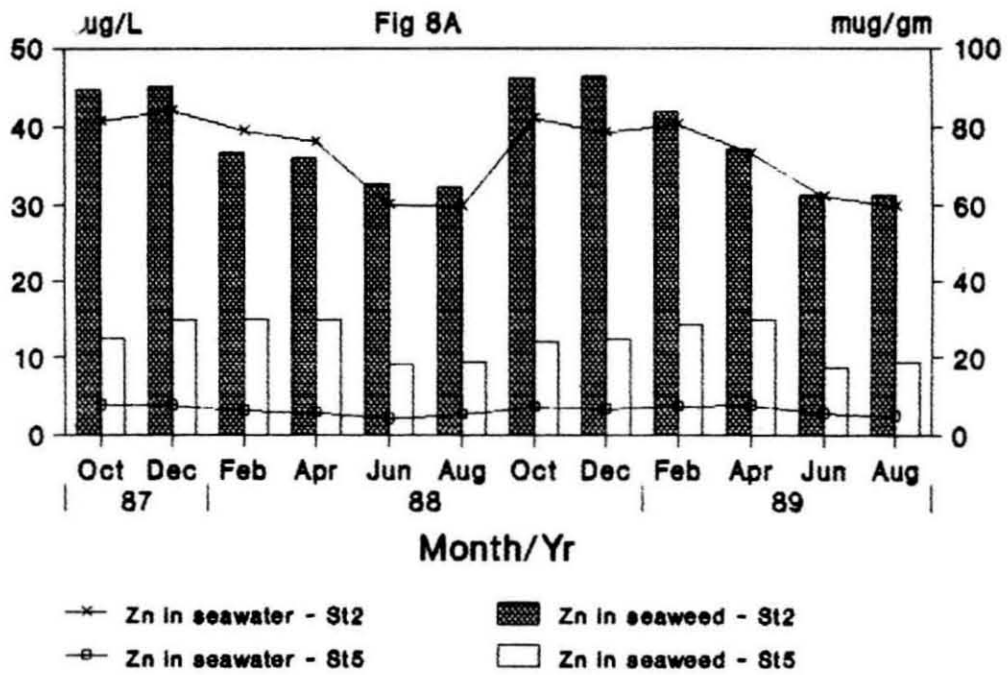
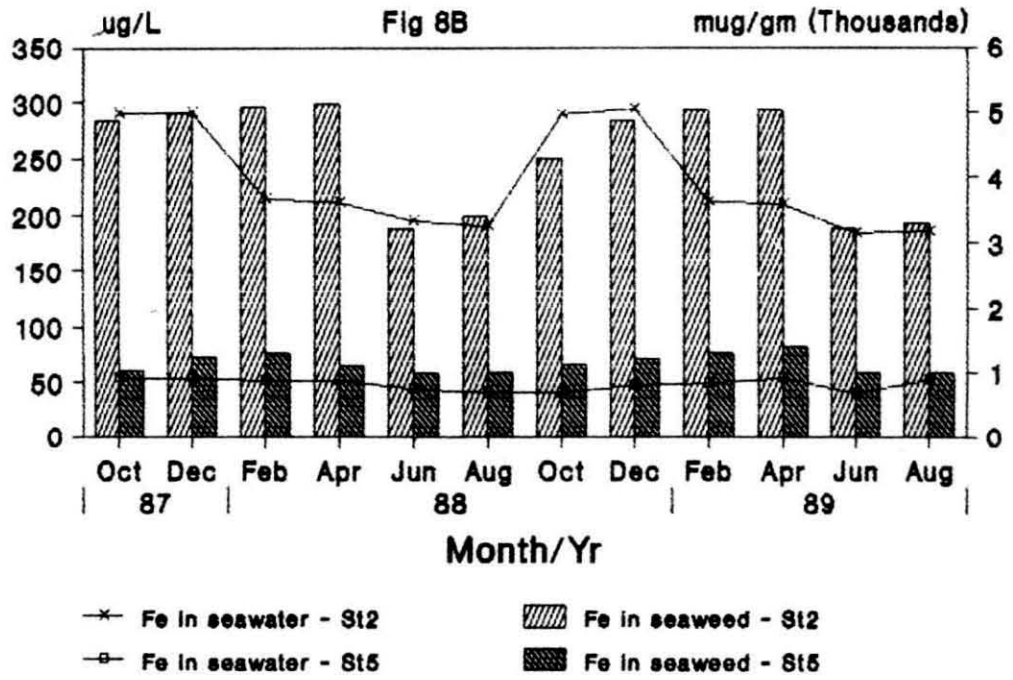


Fig 8B : Iron in seawater and Chaetomorpha linum at stations 2 and 5

Iron in Seawater and C.linum



DISCUSSION

The concentration of heavy metals in seawater at hot water effluent site and waste water site of TTPS is far higher than those reported for natural and other polluted waters (Matkar et al., 1981; UNEP, 1985; Kannan et al., 1992). The concentration of metals in seawater is of the order Cu > Ni > Zn > Pb. Roessler and Zieman (1970) also observed high concentrations of iron and copper at thermal effluent site of Biscayne Bay, Florida. Burning of coal in thermal power station produces chemically complex ash wastes which are disposed into nearby aquatic systems. At Tuticorin Bay the source of heavy metal in seawater and sediment is flyash. Apart from flyash, the heavy metals may also originate from corrosion of screen surfaces or from tubing and piping in cooling water systems. Cooling water pipes are made of cupronickel. The major heavy metals leaching out of flyash are copper, lead, nickel and zinc (Aggarwal and Thakre, 1988). Among Tuticorin Coast pollution due to effluent discharge from textile, fertilizer and chemical plants have been reported (Anon., 1992). Ganesan et al.(1991) attributed high levels of metals in seaweeds at Tuticorin to pollution from ash disposal of thermal power station, busy harbour activities and coal and oil jetty operations.

The concentration of heavy metals except iron in sediment is of the order Ni > Cu > Zn > Pb. The high values of stations 1 and 2 is because the bottom at these areas are mainly composed of sedimented flyash. At station 2 an additional input is settling of particles from the waste water pipes to the bottom from the water column. At the other stations the organic-rich clayey layer may also show a high capacity for accumulating heavy metals (Schintu et al., 1991). A marked seasonal variation in concentration of heavy metal in seawater and sediments observed in the present study. In general, the concentration is high during the northeast monsoon (October to January) and postmonsoon (February to May). Ganesan and Kannan (1995) opined that these high concentrations are due to increased inputs of land runoffs.

The heavy metal accumulation by E.compressa and C.linum were higher than that of G.verrucosa except in the content of nickel. Rao et al.(1995) found that green algae concentrate more trace metals than brown or red algae. The copper, zinc and iron values of E.compressa obtained from the polluted sites are comparable to the values reported by Ganesan et al.(1991). However, the nickel, zinc and iron values for G.verrucosa is higher than reported by Agadi et al.(1978) at Goa Coast. The excess copper in G.verrucosa is bound by polysaccharides (Zoltukhina and Gavrilenko, 1992). There seems to be a direct relationship between carbohydrate of G.verrucosa and its copper

content. The uptake of certain metals in seaweeds is a passive process involving ion exchange sites in the cell wall (Myklestad and Eide, 1978). Ilyas and Sukan (1994) observed that the level of heavy metal in G.verrucosa was high but did not reach toxic levels in a highly eutrophicated system. At the waste water effluent site of TTPS, the copper and zinc concentrations of the three species studied were higher than the permissible limit prescribed for seafoods.

Significant seasonal variation is observed only in the case of zinc in G.verrucosa and C.linum, while variations of nickel and zinc are important for E.compressa. These observation indicate that uptake of metal in algae are not dependent on environmental factors such as temperature and salinity. Sfriso et al.(1995) observed that the uptake of metal in macroalgae was controlled by seasonality and frond age. The metal uptake is also influenced by phenology (Rao and Indusekhar, 1989) and growth dynamics, the age of the tissue, the metal concentration in the environment and abiotic factors such as salinity and temperature (Haritonidis and Malea, 1995). In the present study the significant seasonal variation is more dependent on the concentration of metals in ambient waters.

The correlation of environmental parameters, metals in seawater and sediment with metals in seaweed indicate that at the

waste water effluent site, all the parameters contribute significantly to metal uptake. Temperature can indirectly affect metal uptake in algae by directly affecting growth. Since metal levels in newly synthesized tissues are often lower than in older parts of the plant (Bryan and Hummerstone, 1973). The ability of seaweeds to accumulate metals may be enhanced at higher metabolic rate caused by higher temperatures. Factors which can influence metal uptake in marine algae include nutrient availability (Ilyas and Sukan, 1994), light intensity and water turbidity (Phillips, 1977).

Concentration of metals in seawater and sediment are equally important for the uptake by algae as indicated for G.verrucosa and E.compressa at station 2. Ganesan and Kannan (1995) did not observe any correlation between sediment and algal metal concentrations. They concluded that algae accumulate metals mainly from surrounding water medium. However, Malea et al. (1995) found that the uptake of metals by Dasycladus vermicularis were correlated with their concentration in the sediment and not with their dissolved level in seawater. The higher uptake of metals by algae during monsoon at Tuticorin Bay suggest that the resuspension of bottom deposits by wind and wave action releases metals into the water column which are absorbed by the seaweeds.

The biioaccumulation of metals by G.verrucosa and E.compressa shows that they can tolerate a high level of pollution and hence can be used as "indicator species" of heavy metal pollution along the Indian coast. The metal content of seawater and sediment at the thermal and waste water pollution site are many fold greater than that for natural waters indicating a high level of pollution. The concentration of metals in seawater and sediments are equally important for the uptake of metal by algae. The copper and zinc concentration of seaweeds are far greater than the permissible limits for human consumption and thus influences the aquatic food chain of the ecosystem. There is immense scope for future studies in bioaccumulation of chemical microbiocides through seaweeds. Seaweeds can be taken as indicator species in stress related studies.

1. The present investigation deals with the hydrography, physiology of seaweeds and the heavy metal concentration of seawater, sediment and algae from the discharge sites of Tuticorin Thermal Power Station (TTPS).

2. The average monthly water temperature in the Toticorin Bay just off the hot water site is 10.3 to 11.5 ^{o}C more and forms a thermal plume of an rea covering approximately 1.5 sq. km.

3. The maximum phytoplankton production observed at hot water effluent site is only 0.05 gC/cub.m/day showing a 30 fold decrease in production compared to the control site.

4. Salinity and pH does not show significant variation between stations.

5. At hot water effluent site, the values of phosphate and nitrate were comparatively lower than the other stations.

6. The hydrological parameters studied shows significant variation between stations and not related with seasons except for values of silicade.

7. The total absence of seaweed vegetation at hot water site clearly indicate that seaweeds cannot survive at 40 ^{o}C.

8. Temperature increments of 7-8 ^{o}C between thermal effluent site and waste water site, resulted in the survival of hardy local species, resistant to warm water and effective at colonizing disturbed areas.

9. The only algal vegetation observed at the waste water site were : Gracilaria verrucosa, Enteromorpha compressa and Chaetomorpha linum.

10. A combination of increased temperature and turbidity leads to reduced net production by seaweeds and chlorophyll content at waste water effluent site.

11. The protein, carbohydrate and lipid of algae from the waste water site was less than the control stations.

12. Concentration of heavy metals in seawater at hot water and waste water effluent sites of TTPS is far higher than those reported for natural and other polluted waters.

13. At Tuticorin Bay, the source of heavy metal in seawater and sediment is flyash, hot water and waste water.

14. The concentration of metals in seawater is of the order Cu > Ni > Zn > Pb and in sediment Ni > Cu > Zn > Pb.

15. A marked seasonal variation in concentration of heavy metals in seawater and sediment is observed.

16. Correlation of environmental parameters, metals in seawater and sediments with metals in seaweed indicate that at the waste water effluent site, all the parameters contribute significantly to metal uptake.

17. The bioaccumulation of metals by G.verrucosa and E.compressa show that they tolerate a high level of pollution and hence can be used as "indicator species" of heavy metal pollution along the Indian coast.

18. Copper and zinc concentrations of seaweeds are far greater than the permissible limits for human consumption.

19. Tuticorin Bay which forms a part of Gulf of Mannar is declared as a Biosphere Reserve to preserve the genetic diversity of this marine ecosystem.

20. This study reveals that the dumping of thermal and waste effluents and flyash into Tuticorin Bay has caused extensive damage to this fragile system.

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